



Pacific Ocean, Cabrillo National Monument (photo P. Gonzalez)

Anthropogenic Climate Change in Cabrillo National Monument, California, USA

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Abstract

Greenhouse gas emissions from cars, power plants, and other human sources have caused anthropogenic climate change and impacts on ecosystems and human well-being. To assist in the integration of climate change science into resource management in Cabrillo National Monument, California, this report presents information on climate change trends, historical impacts, future risks, and carbon in the park. Spatial analyses of historical climate data at 800 meter spatial resolution show that annual average temperature of the area within park boundaries increased at a statistically significant rate of $1.8 \pm 0.2^{\circ}\text{C}$ ($3.2 \pm 0.4^{\circ}\text{F.}$) per century (mean \pm standard error) from 1895 to 2016. During that period, annual precipitation showed no statistically significant trends. A scientific literature review shows that field research in the region has detected historical changes attributed mainly to anthropogenic climate change: sea level rise of 25 ± 2 cm (10 ± 1 in.) in San Diego from 1906 to 2018, increase of sea surface temperature of $0.8 \pm 0.2^{\circ}\text{C}$ ($1.4 \pm 0.4^{\circ}\text{F.}$) in the California Current of the Pacific Ocean from 1920 to 2016, increase in acidity of 40% (-0.15 pH) in ocean waters off the coast of San Diego since ca. 1750, reduction of oxygen of $4 \pm 1\%$ in the northern Pacific Ocean from 1960 to 2010, and a 30 ± 17 km northward shift of winter bird ranges across the lower 48 US states, including in the San Diego area, from 1975 to 2004. Under the highest greenhouse gas emissions scenario of the Intergovernmental Panel on Climate Change (Representative Concentration Pathway [RCP] 8.5), thirty-three climate models project an increase of annual average temperature of the park of $3.8 \pm 0.9^{\circ}\text{C}$ ($6.8 \pm 1.6^{\circ}\text{F.}$) from 2000 to 2100. Cutting emissions from human activities (RCP2.6) to meet the Paris Agreement goal could reduce projected heating by two-thirds. Approximately half the climate models project increases in precipitation and half project decreases, although higher temperatures would tend to increase aridity. Published analyses indicate that continued climate change could increase numerous risks: inundation of intertidal habitat from sea level rise, coastal erosion from storm surges, damage to intertidal marine life from hotter temperatures, increased wildfire potential, and increases in invasive plant species. Vegetation in the park stores $98 \text{ tons} \pm 9 \text{ tons}$ of carbon in aboveground biomass. As long as the vegetation remains, it prevents that carbon from contributing to climate change. Motor vehicles of staff and visitors generate 74% of the 72 tons per year of park carbon emissions, pointing to ways to help reduce the human cause of climate change.

Introduction

Greenhouse gas emissions from cars, power plants, deforestation, and other human activities have caused climate change (IPCC 2013, USGCRP 2017). Field research shows that human-caused climate change is altering ecosystems and affecting the well-being of people by melting glaciers, raising sea level, aggravating wildfire, increasing tree death, contributing to animal extinctions, and causing other impacts globally (IPCC 2014), across the United States (USGCRP 2018), and in United States national parks (Gonzalez 2017).

In response, national parks are developing resource management strategies for conservation under climate change. To assist in the integration of climate change science into resource management in Cabrillo National Monument, this report presents published results of spatial analyses of historical and projected climate trends (Gonzalez et al. 2018) and an assessment of published scientific research on historical impacts of climate change, future risks, and carbon.

Methods

Historical climate This report presents results of spatial analyses of historical climate trends (Gonzalez et al. 2018) from previously published climate data layers at a spatial resolution of 800 meters, derived from point weather station measurements using the Parameter-elevation Relationships on Independent Slopes Model (PRISM; Daly et al. 2008). PRISM uses elevation and topography to interpolate climate values in the spaces among weather stations. This report summarizes results by giving trends for the area within park boundaries as a whole and maps of the spatial patterns of climate trends across the park and surrounding area.

Linear regression of temperature and precipitation time series gives the historical climate trends, with the statistical probability of significance corrected for temporal autocorrelation. Analyses of monthly, seasonal, and annual climate were originally run for the periods 1895-2010 and 1950-2010, the data available at the time of the original research. Additional analyses of annual trends were later run for the period 1895-2016. The time periods starting in 1895 provide the longest available weather station-based trends for the area of the park, but the configuration of the US weather station network stabilized in the 1950s (Vose et al. 2014), so the period starting in 1950 gives a trend based

on a more consistent set of stations.

Projected climate This report presents spatial analyses of future projections of climate (Gonzalez et al. 2018) that use output of all available general circulation models (GCMs) in the Coupled Model Intercomparison Project Phase 5 dataset developed for the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC 2013). The coarse-scale GCM output, at spatial resolutions of up to 200 km, has been downscaled to 800 m spatial resolution using the bias correction and spatial disaggregation method (Wood et al. 2004) and the PRISM historical climate time series as a base layer (Daly et al. 2008). Future projected changes are expressed as the change from the standard 1971-2000 historical baseline.

IPCC has coordinated research groups to project possible future climates under four defined greenhouse gas emissions scenarios, called representative concentration pathways (RCPs; Moss et al. 2010). The four emissions scenarios are RCP2.6 (reduced emissions from energy efficiency and of renewable energy, achieving the goals of the Paris Agreement (UNFCCC 2015)), RCP4.5 (low emissions), RCP6.0 (high emissions, somewhat lower than continued current practices), and RCP8.5 (highest emissions, no emissions reductions). Climate under each of the four scenarios was projected by up to 33 GCMs. The four emissions scenarios determine the overall range of potential futures. Within each scenario, the spread of projections of the GCMs generates a range of potential futures, characterized here by the average and standard deviation of the GCM ensemble for each scenario.

Historical impacts and future risks This report also assesses information on historical impacts of climate change, future vulnerabilities, and carbon. The impacts and vulnerability information come from a search of the Clarivate Analytics Web of Science, the authoritative database of scientific literature, for published research that used field data from Cabrillo National Monument or the surrounding San Diego area or which examined the climate sensitivity of species, ecosystems, or other resources found in the park.

Carbon Ecosystem carbon data come from a previously published statewide analysis of remote sensing and field data (Gonzalez et al. 2015). Analyses of Landsat remote sensing and field measurements of biomass across the state of California produced estimates of the carbon in aboveground vegetation for the grasslands, woodlands, forests, and other non-agricultural and

non-urban areas of the state at 30 m spatial resolution (Gonzalez et al. 2015). Monte Carlo analyses of error in tree measurements, remote sensing, and the carbon fraction of biomass quantified the uncertainty of carbon stock change estimates. Validation of the carbon stock estimates by independent stock estimates derived from measurements at field sites found that the new results were close to field-derived estimates (Gonzalez et al. 2015).

Historical Climate Trends

Temperature Average annual temperature increased at a statistically significant rate of $1.8 \pm 0.2^{\circ}\text{C}$ ($3.2 \pm 0.4^{\circ}\text{F.}$) per century (mean \pm standard error) from 1895 to 2016 for the area within park boundaries (Figure 2) (Gonzalez et al. 2018). Seasonally, temperatures from 1895 to 2010 increased at the highest rates in autumn and winter (Table 1). Monthly temperatures increased at statistically significant rates for all 12 months since 1895 and for five months since 1950 (Table 1).

Spatially, temperature increases were highest north of the park, on Point Loma Peninsula, and near downtown San Diego (Figure 2). The heat storing capacity of concrete, asphalt, and steel and other characteristics of a city create an urban heat island, an area of temperatures higher than surrounding unbuilt areas. The urban heat island of Los Angeles and San Diego increases night-time temperatures by 3.1°C (5.6°F.) and daytime temperatures by 1.3°C (2.3°F.), compared to historical pre-urbanized conditions (Vahmani et al. 2016).

Precipitation Historical annual and seasonal precipitation showed no statistically significant trends for the area within park boundaries (Table 2, Figure 3) (Gonzalez et al. 2018). The trends for the period 1895-2010 (Table 2) and 1895-2016 (Figure 3) do not agree and neither was statistically significant. This is due to the high inter-annual variability of rainfall in the San Diego area and lack of a directional change in annual precipitation (Easterling et al. 2017). Spatially, annual precipitation showed numerical increases on the Point Loma Peninsula and numerical decreases inland (Figure 4).

For the southwestern US as a whole, extreme storms have increased in the past half-century, with the amount of precipitation in 20-year events (a day with more precipitation than any other

day in 20 years) increasing in all four seasons from 1948 to 2015, a trend attributable in part to anthropogenic climate change (Easterling et al. 2017).

Drought A severe drought struck most of California, including the San Diego area, from 2012 to 2016, with the lowest 12-month precipitation total combining with the hottest annual average temperature in the period 2012-2014 (Diffenbaugh et al. 2015). Analyses of the Palmer Drought Severity Index (PDSI), an indicator of near-surface soil moisture, for the period 1901-2014 indicate that 2014 was the driest year in the record in the San Diego region (Williams et al. 2015). Climate water deficit, the difference between potential and actual evapotranspiration, had already increased from 25 mm per year to 130 mm per year between the periods 1900-1939 and 1970-2009, indicating that conditions became more arid (Rapacciuolo et al. 2014).

Analyses of PDSI for the period 1896-2014 showed that, while the probability of low precipitation years has not increased, the hotter temperatures of human-caused climate change have increased the probability of drought by increasing the probability of high temperature and low precipitation occurring at the same time (Diffenbaugh et al. 2015). For the State of California as a whole, the high temperatures of anthropogenic climate change accounted for one-tenth to one-fifth of the 2012-2014 period of the drought (Williams et al. 2015).

El Niño-Southern Oscillation (ENSO) ENSO is a recurring natural climate pattern across the tropical Pacific that causes relatively predictable changes in temperature and precipitation during the warm phases (El Niño) and the cold phases (La Niña), every two to seven years. El Niño causes warmer than average ocean water temperatures off San Diego and more winter rain. Conversely, La Niña causes cooler than average ocean water temperatures off San Diego and less winter rain. Historical climate change has not changed the frequency of ENSO (IPCC 2013, Timmermann et al. 2018, Yeh et al. 2018).

Historical Impacts

Changes detected in the region and attributed to anthropogenic climate change

Published research that includes data from southern California or the Pacific Ocean off the coast of southern California has detected changes that are statistically significantly different from

natural variation and has attributed the cause of those changes to anthropogenic climate change more than other factors.

Sea level rise At the National Oceanic and Atmospheric Administration (NOAA) tidal gauge on the USS Midway pier in San Diego, measurements show that sea level increased 25 ± 2 cm (10 ± 1 in.) (mean \pm standard error) from 1906 to 2018 (NOAA, https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9410170) (Figure 6). This tidal gauge has contributed to global analyses that have detected a statistically significant rise in global sea level from 1901 to 2012 (Church and White 2011, Dangendorf et al. 2017, IPCC 2013). Analyses of potential causal factors attribute this rise to anthropogenic climate change through runoff from the melting of glaciers and other land ice and the expansion of ocean water when it warms (IPCC 2013, Slangen et al. 2016).

Ocean warming Measurements from buoys and ships off the California coast and around the world, combined with remote sensing data, have found that the average sea surface temperature of the California Current of the Pacific Ocean increased of $0.8 \pm 0.2^{\circ}\text{C}$ from 1920 to 2016 (Jacox et al. 2018, Rayner et al. 2003) and analyses of casual factors attributed this to anthropogenic climate change (IPCC 2013). The ocean temperature gauge at Scripps Pier, approximately 20 km (12 mi.) north of the park, recorded the highest daily high temperatures since 1916 from August 2 to 10, 2018, and a temperature record of 27°C (81°F.) on August 6, 2018 (Scripps Institution of Oceanography, <https://scripps.ucsd.edu/programs/shorestations>, http://www.sccoos.org/data/piers/timeline/?main=single&station=scripps_pier). Anthropogenic climate change has also caused substantial ocean warming to a depth of 2000 m (Levitus et al. 2012, Abraham et al. 2013, IPCC 2013, Ishii et al. 2017, Cheng et al. 2017, Resplandy et al. 2018, Cheng et al. 2019).

Ocean acidification Increased atmospheric carbon dioxide (CO_2) concentrations from human activities are increasing the acidity of ocean water globally as the CO_2 dissolves in water and forms carbonic acid. Analyses of ocean water samples just off the coast of San Diego show that anthropogenic CO_2 has increased ocean water acidity 25% to 40% (-0.10 to -0.15 pH) from the preindustrial era (ca. 1750) to the early 2000s (Carter et al. 2017, Feely et al. 2016, Gruber et al. 2012, IPCC 2013). Ocean upwelling along the Pacific

Coast can produce acidification episodes within 10 km of the shore of more than a doubling of acidity (-0.4 pH) at Lompoc in central California (Chan et al. 2017). Globally, ocean acidification has caused mortality in mollusks, reduced calcification in corals, coccolithophores (a type of phytoplankton), and mollusks, and reduced growth in mollusks, echinoderms, and crustaceans (Kroeker et al. 2013). Along the California coast, ocean acidity has increased more rapidly than the natural rate at which some small planktonic sea snails (pteropods) can increase their shell calcification, leading to dissolving of their shells and death (Bednaršek et al. 2014, Busch et al. 2014, Bednaršek et al. 2017).

Ocean deoxygenation The solubility of oxygen decreases as the temperature of water increases. As a result, ocean warming has reduced oxygen concentrations in the California Current by 20% from 1980 to 2012 (Bograd et al. 2015, Ito et al. 2017, Schmidtke et al. 2017). Dissolved oxygen is essential for the survival of marine mammals and other marine life.

Bird range shifts Analyses of Audubon Christmas Bird Count data across the US, including the count in San Diego, detected a northward shift of the winter range of a set of 254 bird species, at a rate of 0.5 ± 0.3 km (0.3 ± 0.2 mi.) per year from 1975 to 2004, attributable more to climate change than other factors (La Sorte and Thompson 2007). Lesser Scaup (*Aythya affinis*), one of the species shifting north and a species listed by the National Park Service (NPS) Inventory and Monitoring Program (NPS 2018) as present in the park, has shown a statistically significant reduction in the San Diego count since 1975. Additional analyses found northward shifts across the US from 1975 to 2011 of winter distributions of five raptor species listed (NPS 2018) as present in the park: American Kestrel (*Falco sparverius*), Golden Eagle (*Aquila chrysaetos*), Northern Harrier (*Circus cyaneus*), Prairie Falcon (*Falco mexicanus*), and Red-tailed Hawk (*Buteo jamaicensis*) (Paprocki et al. 2014).

Wildfire increase, western US Wildfire is an essential component of many forest, shrubland, and grassland ecosystems, facilitating germination of new seedlings, killing pests, and serving other critical functions. Excessive wildfire, however, can damage ecological integrity (Hessburg et al. 2016, Stephens et al. 2014) and harm people. Because Cabrillo National Monument is surrounded by US Navy and US Coast Guard

bases and is near to residential areas, the park suppresses all fires to protect from property damage.

Statistical analyses of historical wildfire, climate, and fuels across the western US showed that anthropogenic climate change doubled wildfire area from 1984 to 2015 (Abatzoglou and Williams 2016). The hotter temperatures of anthropogenic climate change combined with statistically significant decreases of summer rainfall from 1979 to 2016 to increase burned area across the western US (Holden et al. 2018). Multivariate analyses of historical wildfires across the western US from 1916 to 2003, including wildfires in California chaparral, indicated that climate was the dominant factor controlling the extent of burned area, even during periods of active fire suppression (Littell et al. 2009).

Changes consistent with, but not formally attributed to human-caused climate change

Other research has found changes consistent with human-caused climate change, but either has not detected changes that are statistically significantly different than historical variability or has not analyzed potential causal factors to formally attribute the cause of the change.

Marine heat waves From 1982 to 2016, marine heat waves (periods in which sea surface temperature of a local area was hotter than temperatures in 99% of the time series) doubled globally (Frölicher et al. 2018), consistent with higher sea surface temperatures due to climate change. The marine heat wave along the Pacific Coast from 2014 to 2016 was partly due to climate change, but the relative contributions of natural variability and climate change are unresolved (Jacox et al. 2018). That episode led to mass strandings of sick or starving birds and sea lions, reduced salmon survival, and increases in harmful algal blooms (Cavole et al. 2016).

Harmful algal blooms Warmer water temperatures can contribute to formation of harmful algal blooms (O'Neil et al. 2012). Harmful algal blooms along the US west coast have increased in the past decade (Gobler et al. 2017, Lewitus et al. 2012). Harmful algal blooms can produce domoic acid, which can kill people who eat tainted shellfish (McKibben et al. 2017, Moore et al. 2008) and can kill California sea lions (*Zalophus californianus*) (McCabe et al. 2016, McKibben et al. 2017, Scholin et al. 2000). Ocean warming off southern California in 2003 and 2004 caused harmful algae blooms and domoic acid contamination

in phytoplankton and fish caught off Scripps Pier (Busse et al. 2006).

Intertidal invertebrate changes Resurveys in 2002 of mussel bed communities along the California coast, first surveyed in the 1960s and 1970s, found significant declines in species richness, with a 50% loss at Ocean Beach, near the park (Smith et al. 2006). This is consistent with, but not attributed to, ocean warming. Intertidal pool invertebrates, including mollusks and snails, in Monterey Bay, California, similar to those found in Cabrillo National Monument, showed signs of a northern range shift with increasing water temperatures from 1931 to 1996 (Barry et al. 1995, Sagarin et al. 1999).

Sea star mortality Along the Pacific Coast of North America, sea star wasting disease has caused extensive mortality of sea stars in the past decade, including the ochre sea star (*Pisaster ochraceus*) and the sunflower star (*Pycnopodia helianthoides*) (Miner et al. 2018, Harvell et al. 2019). The mortality has coincided with higher sea surface temperatures, with the 2014-2015 causing substantial death of sea stars (Miner et al. 2018, Harvell et al. 2019), although Cabillo National Monument experienced less severe mortality than Scripps reef and Cardiff reef north of the park (Miner et al. 2018).

Fog reduced On the Point Loma Peninsula, summer fog (marine layer cloudiness) was present approximately half the day, May to September, 1996 to 2014 (Jennings et al. 2018). Fog cools summer heat and provides moisture for plants and wildlife. Coastal sage scrub requires the moisture provided by summer fog (Emery et al. 2018). Analyses of stratus cloud ceiling heights at southern California airports indicates that the number of summer fog days decreased approximately 20% at San Diego International Airport from 1973 to 2017 (Williams et al. 2018). This is consistent with reductions of fog at airports along the Pacific Coast of North America from 1950 to 2012 (Schwartz et al. 2014). Increased night temperatures, partly from the urban heat island of Los Angeles and San Diego, have contributed to the fog decline in Southern California (Williams et al. 2015).

Wildfire increase, southern California From 1959 to 2009, the area burned by Santa Ana fires (autumn) and non-Santa Ana fires (summer) increased (Jin et al. 2014). Temperatures increased significantly during this period, but the relative importance of climate, urbanization, population growth, and other factors have not been determined.

Reductions of live fuel moisture and increases of burned area in Southern California were significantly correlated with reduced fog from 1973 to 2017 (Williams et al. 2018). No increase of wildfire has occurred in Cabrillo National Monument because federal agencies have been suppressing fire on Point Loma Peninsula for decades.

Future Climate Projections

Temperature Under the highest emissions scenario (RCP8.5), average annual temperature of the area within park boundaries would increase $2.1 \pm 0.5^{\circ}\text{C}$ ($3.8 \pm 0.9^{\circ}\text{F.}$) by 2050 (Table 3) and $3.8 \pm 0.9^{\circ}\text{C}$ ($6.8 \pm 1.6^{\circ}\text{F.}$) by 2100, compared to the 1971-2000 baseline (Table 4) (Gonzalez et al. 2018, IPCC 2013). Cutting greenhouse gas emissions from human activities (emissions scenario RCP2.6) could reduce projected heating by two-thirds. GCMs project the highest temperature increases in autumn (September to November). Projected temperature increases are similar across the park (Figure 7).

For the San Diego area, models project a doubling of the number of days with a maximum temperature greater than 35°C (95°F.) to 40 to 60 days per year under a high emissions scenario (SRES A2, IPCC 2007) (Kunkel et al. 2013). For Point Loma Peninsula, models project an increase in the hottest day of the year of 5°C (10°F.) to as high as 43°C (110°F.) under RCP8.5 (Kalansky et al. 2018).

Precipitation For the area within park boundaries, approximately half of the GCMs project increases and half project decreases (Figure 6). This lack of agreement exists for monthly, seasonal, and annual projections for 2050 (Table 5) and 2100 (Table 6). While the net ensemble average is positive, the projected change is not statistically significant. Even if precipitation increases, increasing temperatures would tend to increase aridity through an increase in evapotranspiration, with a projected increase in climate water deficit for the Point Loma Peninsula of up to 10% by 2069 under RCP8.5 (Kalansky et al. 2018). Summer fog (marine layer cloudiness) is currently controlled by processes that computer modeling cannot accurately estimate, so no future projections are available (Clemesha et al. 2016). Spatially, projected precipitation changes are similar across the park (Figure 8).

For the San Diego area, models project increases in precipitation extremes (Polade et al. 2014, 2017, Jennings et al. 2018, Kalansky et al. 2018). Under the highest emissions scenario, models project the frequency of dry years that currently occur once every 20 years could increase to once every 10 years and precipitation on the wettest day of the year could increase 20% to 30% (Jennings et al. 2018).

For the southwestern US as a whole, models project an increase in five-year storms (a two-day period with more precipitation than any other two-day period in five years) to once every three years (low emissions scenario, RCP4.5) or every two years (highest emissions scenario, RCP8.5) (Easterling et al. 2017). Models project a 20% increase in the amount of precipitation in 20-year storms (a storm with more precipitation than any other storm in 20 years) under the highest emissions scenario (RCP8.5), although a projected increase in downpours does not necessarily increase projected total annual precipitation (Easterling et al. 2017).

Atmospheric rivers, narrow bands of highly concentrated storms in that move from the Pacific Ocean into California (Wehner et al. 2017, Warner et al. 2015), are projected to increase in frequency and intensity (Kossin et al. 2017, Hagos et al. 2016, Jeon et al. 2015, Lavers et al. 2015). The number of days per year with precipitation may decrease, however, leading to intense wet periods alternating with more intense droughts (Polade et al. 2014, 2017).

Drought Hotter temperatures caused by anthropogenic emissions of greenhouse gases have increased the probability of drought in California by increasing the probability of high temperature and low precipitation occurring at the same time (Diffenbaugh et al. 2015). For the State of California as a whole, under the highest emissions scenario (RCP8.5), climate change increases the probability of a drought as severe as the 2012-2016 drought to ~100% by 2030 (Diffenbaugh et al. 2015).

For the southwestern US as a whole, under the highest emissions scenario (RCP8.5), the severity of drought by 2100 AD could increase to a level more severe than any since 1000 AD (Cook et al. 2015). Anthropogenic climate change sharply increases the risk of a megadrought, a persistent dry period lasting 10 years or more, with the probability of a megadrought in the San Diego region increasing to 70% to 90% under a temperature increase of 4°C (Ault et al. 2016). Models project five to ten more dry days per year in southern California (Polade et al. 2014).

For southern California, models project a decrease in the number of days of the hot Santa Ana winds of autumn and winter (Hughes et al. 2011, Pierce et al. 2018), as much as one-fifth fewer under medium emissions (SRES A1B, IPCC 2007) by 2050 (Hughes et al. 2011).

El Niño Southern Oscillation The confidence in any specific projected change in ENSO is low (IPCC 2013, USGCRP 2017). Climate models do not agree on projected changes in the intensity or spatial pattern of ENSO (IPCC 2013, USGCRP 2017, Yeh et al. 2018).

Future Risks

Without greenhouse gas emissions reductions from human activities, continued climate change could increase risks of ecosystems and physical resources to substantial changes (IPCC 2013). Published analyses of projected climate change in southern California or on resources found in Cabrillo National Monument has identified numerous risks.

Coastal and Marine Systems

Sea level rise and storm surge Continued climate change under the highest emissions scenario (RCP 8.5) would increase sea level at La Jolla, north of the park, 1.4 m (55 in.) by 2100 (range 0.8 m to 2.4 m [30 in. to 94 in.], 95% probability) (Pierce et al. 2018). A scenario of low emissions (RCP4.5) could limit the increase in sea level to 0.8 m (30 in.) by 2100 (range 0.4 m to 1.4 m [14 in. to 56 in.], 95% probability) (Pierce et al. 2018). Over and above projected sea level rise, daily high tides and storm surge would increase the potential total sea level rise during storms (Figure 9). The daily tidal range is approximately 2 m (6½ ft.) (NOAA, https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9410170). The storm surge on the San Diego coast from a 100-year storm is approximately 15 cm (6 in.), due to the shallow angle of the coast relative to oncoming storm waves (Bromirski et al. 2017). The combination of past and projected sea level rise, daily tidal range, and storm surge could raise sea level 3 m to 3.5 m (9 ft. to 11½ ft.) above 1983-2001 mean sea level by 2100 (Figure 9) (Serafin et al. 2017).

The major future risks of the coast to sea level rise include inundation of land, inundation of intertidal habitat, and erosion of coastal cliffs. Continued climate change under the highest emissions scenario (RCP8.5) could inundate intertidal and other low-lying areas (Caffrey et al. 2018) (Figures 10, 11).

Spatial analyses of Light Detection and Ranging (Lidar) data from 1998 to 2009 along the cliffs of San Diego County found that the cliffs along the Point Loma Peninsula retreated ~1 m at the cliff top and approximately a half meter at the cliff face (Young 2018). Sea level rise was just one factor contributing to this cliff erosion. Modeling of cliff retreat along the coast at Camp Pendleton, north of the park, estimated that a sea level rise of 1.5 m could cause 9 m to 79 m (range 2 m to 163 m) of cliff erosion by 2100 (Young et al. 2014).

Ocean warming Continued climate change could warm California Current waters 2 to 4°C (3.6 to 7.2°F.) above the 1980–2005 average by 2100 (Alexander et al. 2018). This could contribute to more harmful algal blooms (Gobler et al. 2017, McKibben et al. 2017). Under the highest emissions scenario (RCP8.5), the probability of a marine heat wave off the southern California coast could increase from once every 35 years to once every other year (Frölicher et al. 2018). The marine heat wave along the Pacific Coast in 2014-2016 demonstrated the mortality risk to birds, sea lions, and salmon of warmer ocean waters and changes to the food web (Cavole et al. 2016). In addition, under a high emissions scenario (SRES A2, IPCC 2007), 28 fish species could shift northward more than 300 km (190 mi.) by 2050 due to higher sea surface temperatures (Cheung et al. 2015).

Ocean acidification Ocean acidification dissolves the shells of many marine species and, under high emissions, could deplete near-shore waters of calcium carbonate for almost all of the year (Gruber et al. 2012), increasing the vulnerability of many marine species to death. Acidity reduces the water concentrations of calcium carbonate that many marine species, including pteropods, shellfish, and corals, require for building shells for survival. Under a high emissions scenario (SRES A2, IPCC 2007), acidity of California coastal waters could increase 40% (-0.15 pH) above 1995 levels by 2050 (Gruber et al. 2012). Under the highest emissions scenario (RCP8.5), acidity of California Current waters could increase 60% (-0.2 pH) above the 2013 level by 2063 (Marshall et al. 2017). In 2016, Cabrillo National Monument began monitoring ocean acidity, which is providing data on continued acidification in park waters.

Ocean deoxygenation Climate change may reduce ocean oxygen in Pacific Ocean waters to levels lower than any naturally occurring levels as early as 2030 (Long et al. 2016) or 2050 (Henson et al. 2017). Reduced oxygen could decrease rockfish habitat off southern California by 20 to 50% (McClatchie et al. 2010). Further deoxygenation may also shrink open-water habitat for hake (*Merluccius productus*) and other species (Koslow et al. 2017). The reduction of zooplankton with ocean deoxygenation in the Pacific suggests changes in the food webs that could affect marine mammals (Wishner et al. 2018).

Intertidal habitat and species At Cabrillo National Monument, sea level rise could inundate more of the coastal zone, reducing the extent of intertidal habitat. Ocean warming can also reduce intertidal habitat area when suitable temperatures shift upslope. Research in the intertidal zone on Vancouver Island, Canada, found that 0.4 to 0.6°C (0.7 to 1.1°F.) warming of surface waters from 1958 to 2010 reduced the vertical extent of mussel beds by half and contracted predator-free space on rocky shores (Harley 2011).

Warm water temperatures exacerbate the spread of withering syndrome in black abalone (*Haliotis cracherodii*), which has experienced extirpations of across southern California (Neuman et al. 2010, Ben-Horin et al. 2013). Warm water temperatures also increase the onset of withering syndrome in red abalone (*Haliotis rufescens*) in southern California, halting its growth and reproduction (Vilchis et al. 2005). Reproduction in red abalone declines with increasing water temperatures (Rogers-Bennett et al. 2010) and with acidification (Boch et al. 2017).

Off-site rearing of the intertidal aquatic crustacean *Tigriopus californicus* taken from the park (Kelly et al. 2012), Ocean Beach, north of the park (Harada et al. 2019), and other sites along the Pacific Coast found that southern populations exhibit more tolerance to warmer water than northern populations, but that the species does not adapt evolutionarily to temperature increases over time (Kelly et al. 2012).

Ocean warming can also shift the ranges of intertidal species towards the North and South Poles (Helmuth et al. 2006). Ocean acidification increases the vulnerability of corals, coccolithophores (a type of phytoplankton), mollusks, echinoderms, and crustaceans to mortality and reduced calcification and growth (Kroeker et al. 2013). Continued acidification in the California Current could increase mortality of epibenthic invertebrates (crabs, shrimps, benthic

grazers, benthic detritivores, bivalves) (Marshall et al. 2017).

Marine mammals Gray whales (*Eschrichtius robustus*) and humpback whales (*Megaptera novaeangliae*), which migrate along the coast off the park, may spend more time in Arctic waters due to longer and earlier ice-free conditions, delaying their southern migration and changing the duration of their passage through California waters (Moore et al. 2007, Moore and Huntington 2008). One indicator of this has been an increase in gray whale reproduction in the Arctic due to an increase in the ice-free season in the period 1980-2009 (Salvadeo et al. 2015). In addition, marine heat waves can cause increased mortality of sea lions (Cavole et al. 2016).

Terrestrial Ecosystems

Wildfire The hotter temperatures of anthropogenic climate change and increased aridity of vegetation would increase potential fire frequency and burned area across much of California (Mann et al. 2016, Moritz et al. 2012, Westerling et al. 2011). Across southern California, increased temperatures and decreased relative humidity could increase probabilities of Santa Ana fires (autumn) and non-Santa Ana fires (summer) (Jin et al. 2014). Analysis of southern California fire records and climate data for the period 1910-2013 indicates that summer and autumn climate conditions are often sufficient for large fires, so that the coincidence of Santa Ana winds and human ignitions would determine fire occurrence under climate change (Keeley and Syphard 2017).

Under high emissions (scenario A2 of IPCC (2007), higher than RCP6.0 of IPCC (2013)), human-caused climate change may increase potential fire frequency around San Diego by approximately 50% by 2050 (Mann et al. 2016). Point Loma Peninsula, however, is isolated by water bodies and urban areas from the extensive wildlands to the east of San Diego where wildfires generally occur. So, any future wildfire increase in those wildlands would not be able to reach the park. All land managers of the Point Loma Ecological Conservation Area (City of San Diego, National Park Service, US Coast Guard, US Navy) currently suppress any fires that ignite on the peninsula. The fire dependence of chaparral vegetation, the long period of fire suppression in the park, and increased potential wildfire risk under continued climate change suggest a need to explore options for vegetation or fire management that would protect lives and infrastructure, maintain ecological integrity, and prevent post-disturbance spread of invasive species.

Vegetation change The high severity and low frequency fire regime of chaparral naturally causes stand replacement fires from which shrubs will resprout from root crowns. Increases of fire frequency due to anthropogenic climate change can reduce natural regeneration and increase invasive alien grasses, leading to more fire and conversion of chaparral to coastal sage scrub or grassland (Keeley and Brennan 2012, Lippitt et al. 2013, Rachels et al. 2016). After the Cedar Fire east of San Diego in 2003, woolyleaf ceanothus (*Ceanothus tomentosus*) and chamise (*Adenostoma fasciculatum*), both native shrubs, declined in many locations and foxtail chess (*Bromus madritensis*), an invasive alien grass, increased (Keeley and Brennan 2012).

With continued strict fire suppression on the Point Loma Peninsula, however, the park may not experience such vegetation changes, but perhaps experience increases in the maturity of chaparral stands and in the extent of chaparral, at the expense of coastal sage scrub. For the entire range of white coast ceanothus, fire suppression could cause some biomass accumulation (Uyeda et al. 2016). Post-fire biomass in chaparral in San Diego showed substantial increases from seven to 28 years, then modest increases from 28 to 68 years (Uyeda et al. 2016).

Fog is important to the growth of manzanita (*Arctostaphylos spp.*) (Vasey et al. 2012) and Torrey pine (*Pinus torreyana*) (Williams et al. 2008), providing essential moisture in the summer. So, any reduction of fog could affect those species in the park.

Field research in Santa Barbara County indicates that coastal sage scrub also requires summer fog (Emery et al. 2018), so any continued decrease in fog could reduce coastal sage scrub. While urban development, climate change, and increased wildfire may substantially reduce coastal sage scrub habitat in much of the San Diego area, the park could serve as a refugium for coastal sage scrub plant species (Lawson et al. 2010, Riordan et al. 2014).

Invasive plant increase Climate change can favor invasive alien plants in temperate zones, including in the park, for three main reasons:

Carbon dioxide (CO₂) enrichment Invasive alien plants generally exploit atmospheric CO₂ more efficiently than native species, giving them higher growth rates (Davidson et al. 2011, Liu et al. 2017). Carbon enrichment experiments on one invasive alien annual found

in the park, foxtail chess (*Bromus madritensis*), indicated that a doubling of atmospheric CO₂ (equivalent to the high emissions scenario, RCP6.0) could lead to a 20% increase in seeds (Huxman et al. 1999).

Warmth and moisture Increasing warmth and moisture due to climate change can increase the suitability of temperate zone ecosystems to plants from tropical zones (Hellmann et al. 2008, Theoharides and Dukes 2007). Exotic grass species are generally annual, taller, with larger leaves, and larger seeds than native species. Across California, these traits are associated with higher temperature, so exotic grass species are more dominant in warmer areas of the state (Sandel and Dangremond 2012).

A rainfall manipulation experiment at the University of California, Irvine, indicates that coastal sage shrub species, found in the park, can outcompete invasive grasses under lower rainfall, but that invasive grasses are more competitive under higher rainfall (Goldstein and Suding 2014). In addition, under high emissions (SRES A2, IPCC 2007), species distribution modeling indicates that the region would continue to provide suitable habitat for the invasive yellow starthistle (*Centaurea solstitialis*) (Bradley et al. 2009), which is not currently in the park but adjacent to it.

Disturbance Invasive alien plants often proliferate in sites disturbed by physical vegetation removal or by wildfire (Hellmann et al. 2008, Theoharides and Dukes 2007). As described in the sections above on wildfire and vegetation change, invasive plant species can proliferate after a fire in southern California chaparral or coastal scrub (Keeley et al. 2005, Lippitt et al. 2013). Strict fire suppression on the Point Loma Peninsula, therefore, would tend to control invasive plant species. Field research in southern California indicates that, in chaparral or coastal scrub, high woody plant cover is the most important element controlling invasive alien plant invasion and persistence (Keeley et al. 2005).

Anthropogenic climate change causes two disturbances, biome shifts (Gonzalez et al. 2010) and increased wildfire (Abatzoglou and Williams 2016, Littell et al. 2009), which, combined with proximity to ports, roads, and suburban landscaping, lead to a high risk of invasive species in the San Diego area (Early et al. 2016).

Rare plant species An assessment of life history attributes and species distribution models of

156 rare plant species in California identified 42 species as extremely or highly vulnerable to a reduction in population due to climate change (Anacker et al. 2013), but none of those are listed by the National Park Service (NPS 2018) as present in the park.

For Orcutt's spineflower (*Chorizanthe orcuttiana*), listed as endangered under the US and California Endangered Species Acts and present in the park, the only report with detailed information on the species (Bauder 2000) does not provide enough information to characterize its climate sensitivity, although the presence of all extant plants close to the Pacific Coast suggests that it needs cooler temperatures and more fog than would be found in inland sites.

White coast ceanothus (*Ceanothus verrucosus*) is a rare chaparral shrub, found only in southern California, including in the park, and Baja California. It requires fire for most of its germination and recruitment. Increased heat under a high emissions scenario (SRES A2, IPCC 2007) could reduce abundance of white coast ceanothus by half (Lawson et al. 2010). Abundance of white coast ceanothus begins to decline slightly after fire exclusion of 50 years (Lawson et al. 2010).

Birds The California gnatcatcher (*Poliioptila californica*), listed as threatened under the US Endangered Species Act and present in the park, is mainly threatened by loss of coastal sage scrub habitat to suburban development. Research in Riverside County found that colder winter temperatures keep the species at lower elevations, where the bird favors warmer and drier conditions (Hulton VanTassel et al. 2017). No specific analyses, however, of maximum suitable temperature and aridity were conducted.

Research on four coastal sage scrub bird species present in the park – California towhee (*Pipilo crissalis*), rufous-crowned sparrow (*Aimophila ruficeps*), spotted towhee (*Pipilo maculatus*), wrentit (*Chamaea fasciata*) – in Mission Trails Regional Park and San Diego National Wildlife Refuge found lower reproductive success in the low rainfall year 2002 (Bolger et al. 2005). This may have been due to a decrease in insects that provide food for the birds. Research in northern San Diego County found that wrentits delayed egg laying in 2002 (Preston and Rotenberry 2006).

Climate change could continue to shift the ranges of bird species northward across the US (Langham et al. 2015). Modeling of suitable climate for bird species in 2050 indicates that, under

the highest emissions scenario (RCP8.5), the park and a 10 km wide area around the park may gain suitable climate for 39 bird species not currently present in winter and 16 species not currently present in summer but lose suitable climate for eight species in winter and 12 species in summer (Wu et al. 2018). Potential colonizers include the black vulture (*Coragyps atratus*) and the Muscovy duck (*Cairina moschata*). Species vulnerable to extirpation include the American goldfinch (*Spinus tristis*) and Swainson's thrush (*Catharus ustulatus*) (Wu et al. 2018).

Amphibians, Reptiles, Mammals An assessment of 358 amphibian, reptile, bird, and mammal species in California listed as species of concern, threatened, or endangered (California Department of Fish and Wildlife 2016) identified species vulnerable to drought, a possible climate condition in the park. The assessment identified one amphibian species, Pacific slender salamander (*Batrachoseps major*), identified by the NPS Inventory and Monitoring Program (NPS 2018) as present in the park, as highly vulnerable to drought. None of the highly vulnerable mammal and reptile species are present in the park. Research in Joshua Tree National Park indicated that the western fence lizard (*Sceloporus occidentalis*), identified as present in Cabrillo National Monument (NPS 2018), is sensitive to increasing temperatures under climate change (Barrows and Fisher 2014). Research in Organ Pipe Cactus National Monument on side-blotched lizard (*Uta stansburiana*), present in Cabrillo National Monument (NPS 2018), found a substantial population increase from 1989 to 2013 despite an increase in temperature and decrease in rainfall, perhaps due to a reduction in predation (Flesch et al. 2017).

Western monarch butterflies The western population of monarch butterflies (*Danaus plexippus*) breeds in the summer in northern California and the Sierra Nevada and migrates to southern California, including San Diego County, for the winter. Western monarch abundance has declined in breeding areas from 1972 to 2014 and in overwintering areas from 1997 to 2014 (Espeset et al. 2016). Analyses of climate data indicate that climate is not the primary cause of the decline, but habitat loss and pesticide use could be possible causes (Espeset et al. 2016).

Surface ozone pollution The formation of ground-level ozone, a pollutant hazardous to people, increases as temperature increases. Under low emissions (RCP4.5), the number of episodes in the region of the park with ground-level ozone >75 parts per billion could increase up to 12 days by 2050 (Shen et al. 2016).

Carbon

Growing vegetation naturally removes carbon from the atmosphere, reducing the magnitude of climate change. Conversely, tree mortality, from deforestation, wildfire, drought, and other causes, emits carbon to the atmosphere, exacerbating climate change. The balance between carbon emissions from vegetation to the atmosphere and removals from the atmosphere into vegetation determines the role of ecosystems in climate change (IPCC 2013).

Analyses of Landsat remote sensing at 30 m spatial resolution, field measurements of biomass, and Monte Carlo analyses of error in tree measurements, remote sensing, and the carbon fraction of biomass determined this balance across the state of California (Gonzalez et al. 2015). In 2010, aboveground live vegetation in Cabrillo National Monument contained 98 ± 9 tons of carbon (mean \pm 95% confidence interval) (Gonzalez et al. 2015). The highest carbon density in the park occurs in the few patches of coastal sage scrub oak (*Quercus dumosa*) in the park. From 2001 to 2010, the carbon stock in the aboveground vegetation of the park showed no statistically significant change (Gonzalez et al. 2015).

As part of the NPS Climate Friendly Parks program, Cabrillo National Monument has conducted an inventory of greenhouse gas emissions from fossil fuel use in energy, transportation, and waste generation by park operations and visitors (NPS 2010). The analysis estimated total emissions in 2008 of 72 million tons carbon, of which 74% came from cars and other vehicles, 15% from electricity use, and 16% from waste and wastewater. The *Cabrillo National Monument Action Plan* (NPS 2010) identified energy conservation, renewable energy, public transit, and other actions to cut the emissions that cause climate change.

San Diego Metropolitan Transit System bus route 84 directly serves the Cabrillo National Monument visitor center (<https://www.sdmts.com/sites/all/themes/mts/templates/sdg/pdf/84.pdf>). Taking this bus to the park reduces a portion of the greenhouse gas emissions in the park by taking a car off the road. The Intergovernmental Panel on Climate Change has recently confirmed that concerted global action can reduce emissions enough to meet the Paris Agreement goal of limiting future global temperature increase to 1.5 to 2°C (IPCC 2018). The difference between the emissions reductions scenario (RCP2.6) and the highest emissions scenario (RCP8.5), as shown

in Tables 3 and 4 and much of the research cited in this report, shows that cutting carbon emissions from human activities can substantially reduce future heating and risks to the plants, animals, and unique ecosystems of Cabrillo National Monument.

Acknowledgements

Thanks to Andrea Compton (Superintendent, Cabrillo National Monument) and Stacey Ostermann-Kelm (Program Manager, Mediterranean Coast Network, Inventory and Monitoring Program, National Park Service) for helpful comments on the report draft, to staff of the park and the National Park Service Pacific West Region for helpful discussions, and to all at Cabrillo National Monument for a warm welcome to the park.

Figure 1. Average annual temperature, 1895-2016, for the area within Cabrillo National Monument boundaries (Gonzalez et al. 2018).

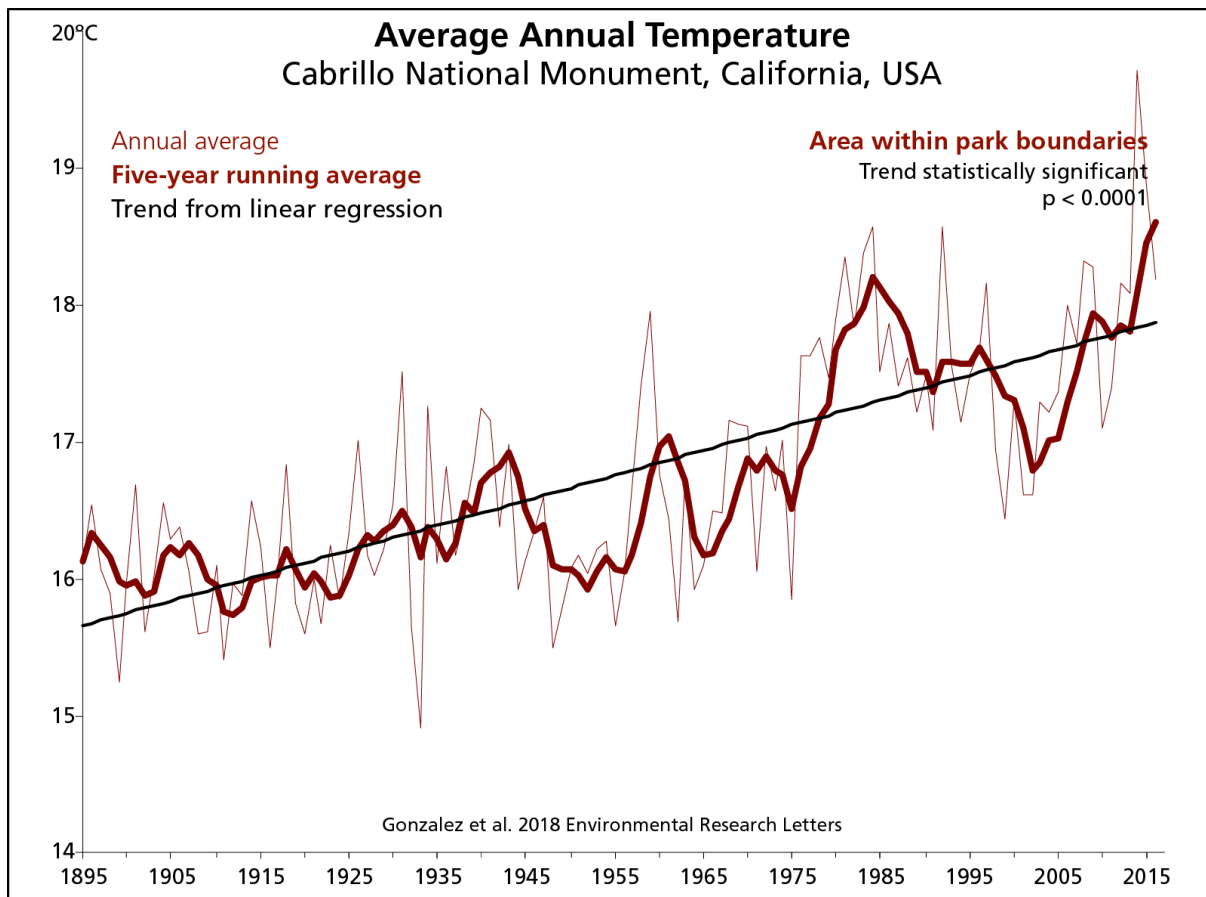


Figure 2. Trend in annual average temperature, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

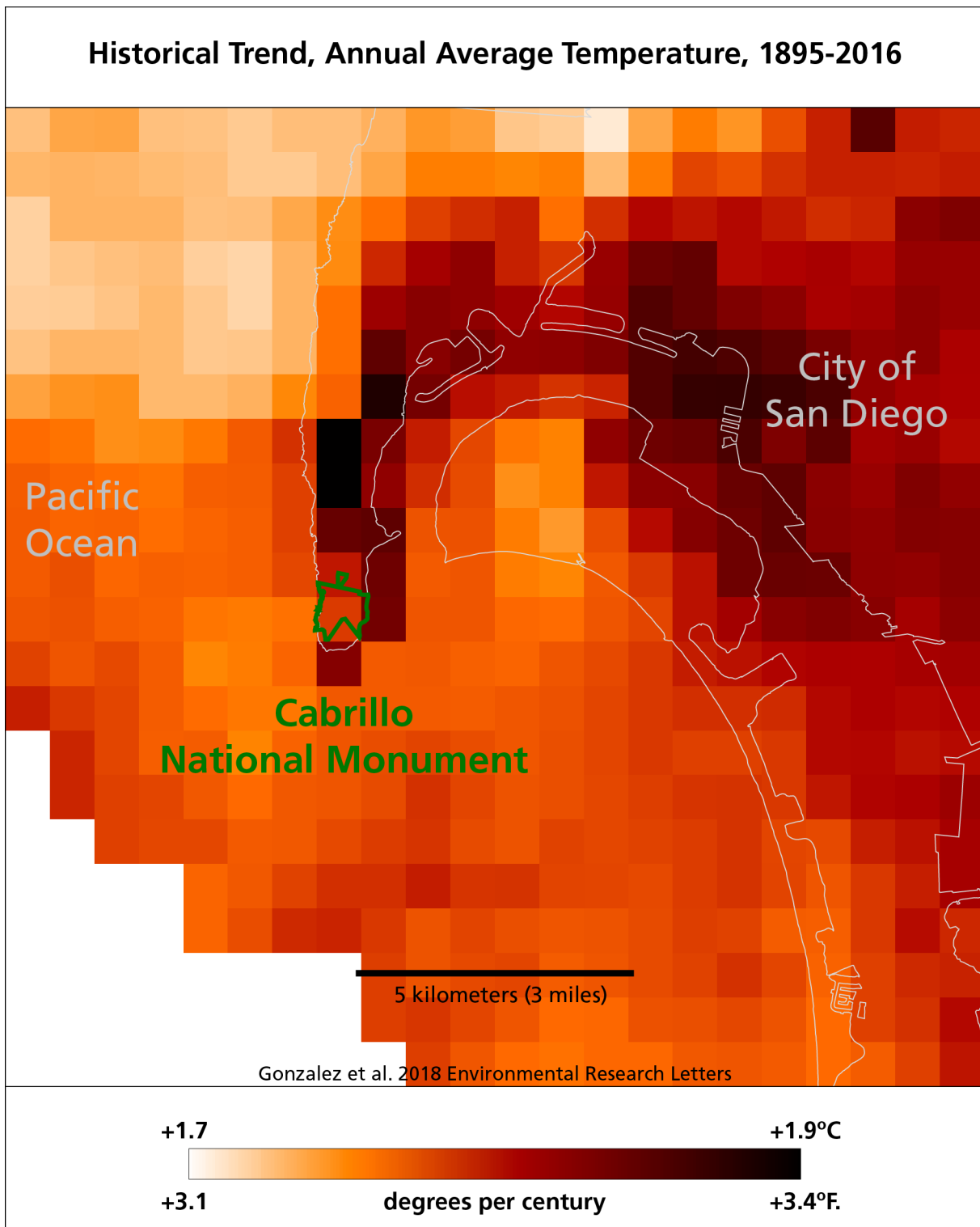


Figure 3. Total annual precipitation, 1895-2016, for the area within Cabrillo National Monument boundaries (Gonzalez et al. 2018).

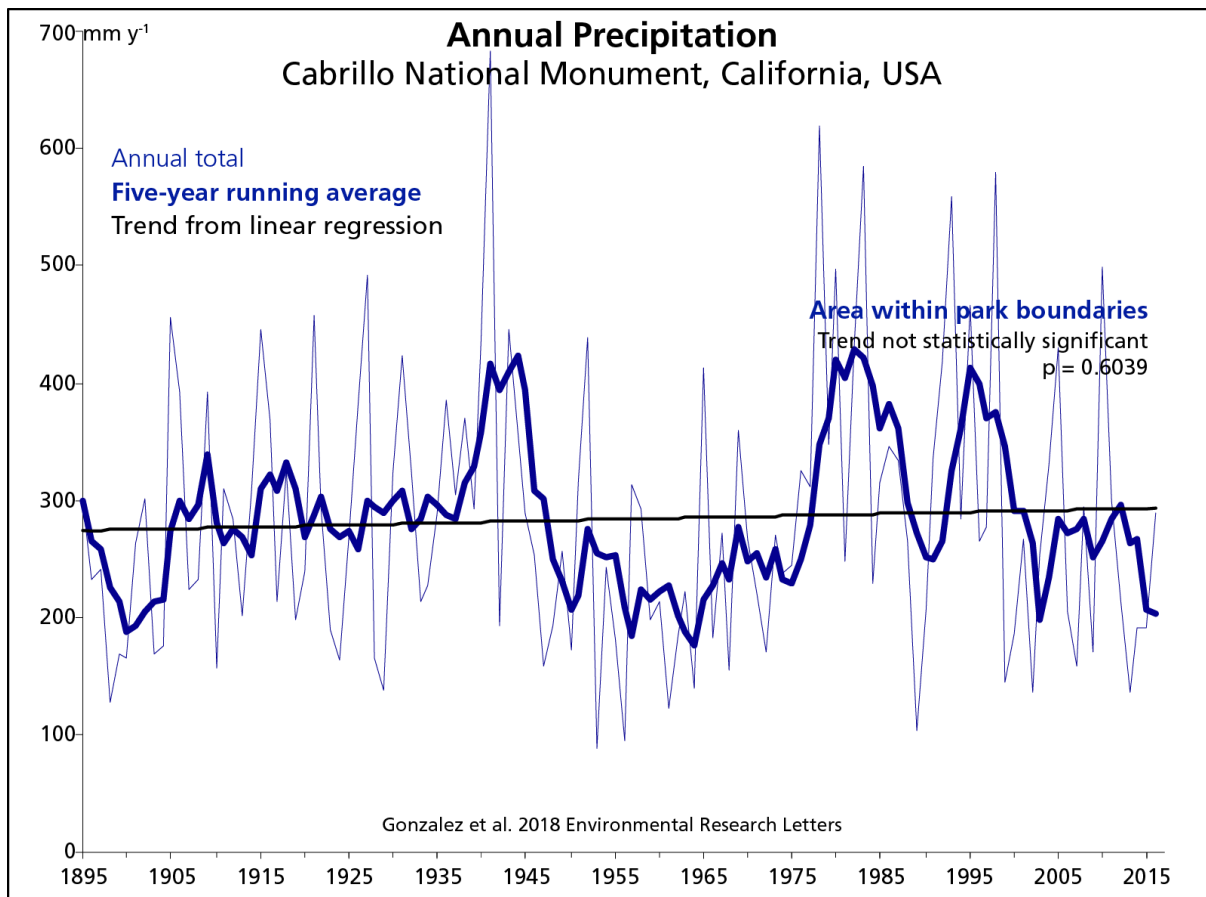


Figure 4. Trend in total annual precipitation, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

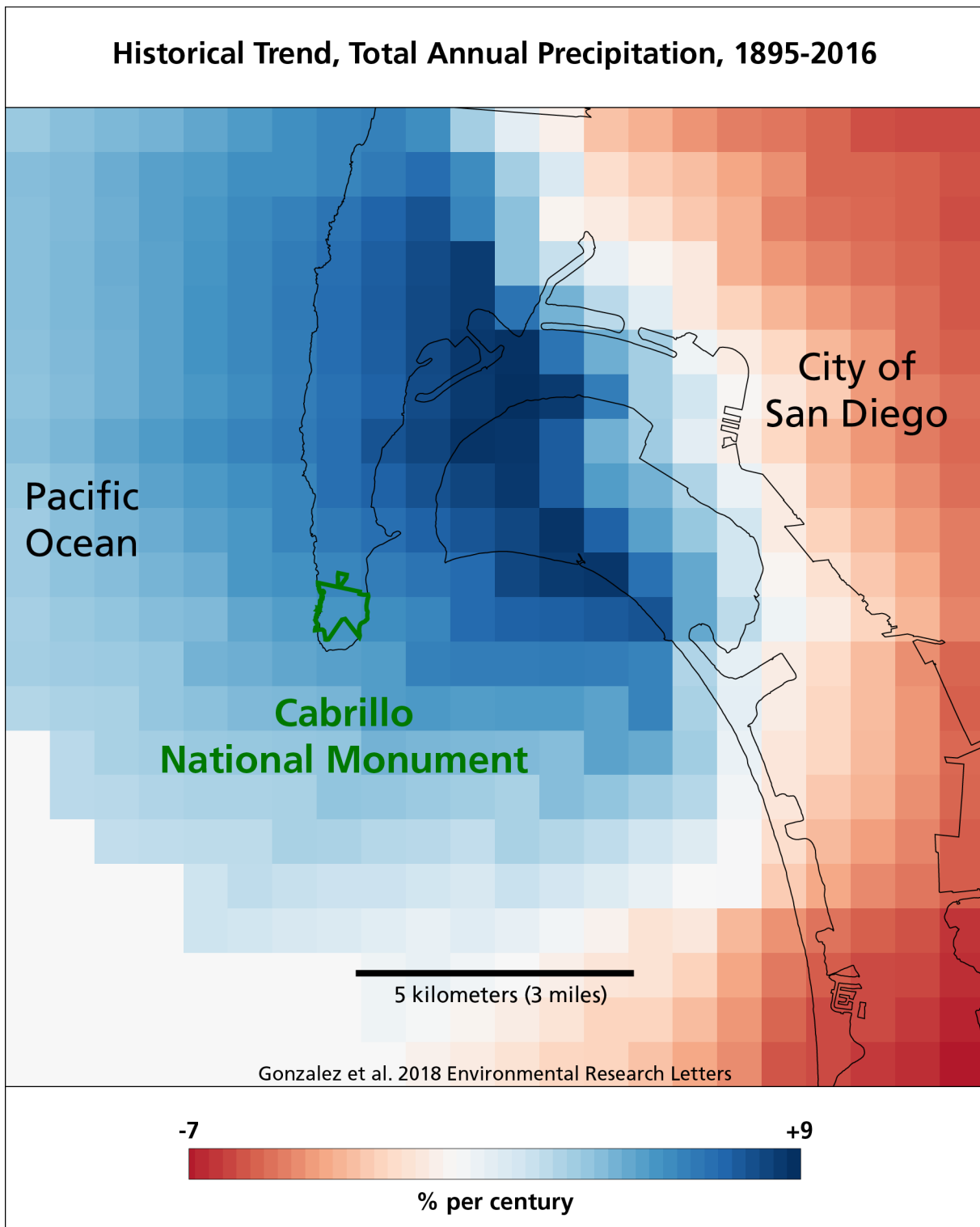


Figure 5. Sea level, 1906-2018, at the tidal gauge on the USS Midway pier in San Diego, California, relative to mean sea level, 1983-2001, the National Tidal Datum Epoch of the US National Ocean Service. The trend, calculated by linear regression corrected for temporal autocorrelation, shows a statistically significant long-term increase.

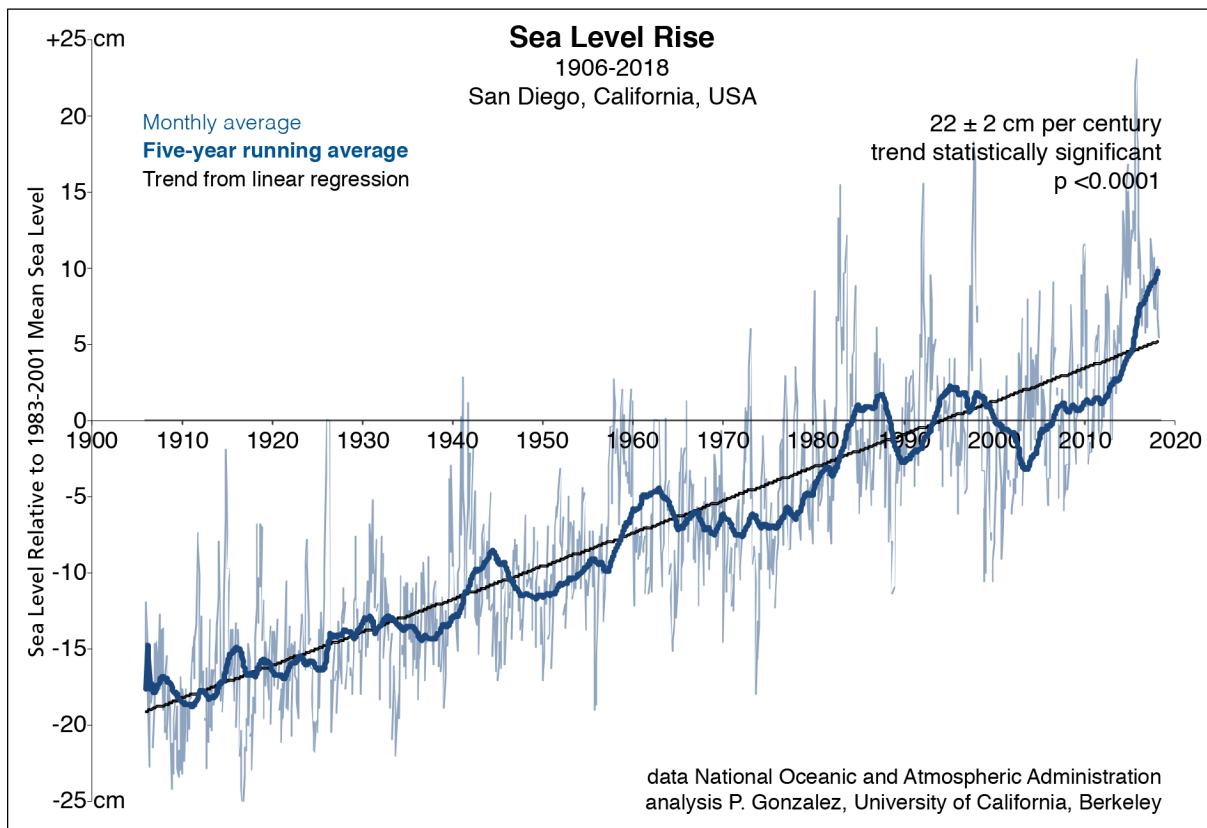
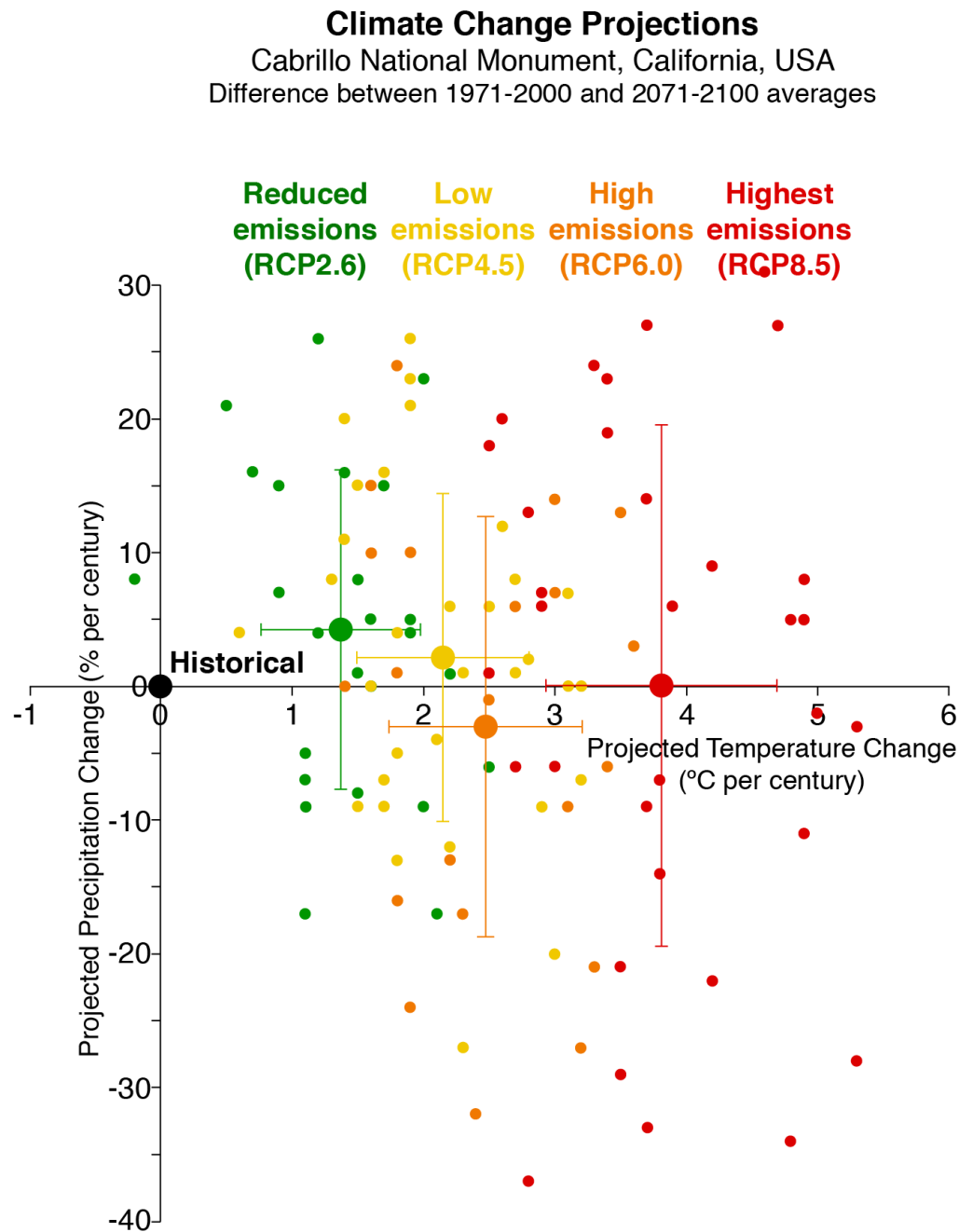


Figure 6. Projections of future climate for the area within park boundaries, relative to 1971-2000 average values (Gonzalez et al. 2018). Each small dot is the output of one of 121 general circulation models. The large color dots are the average values for the four IPCC emissions scenarios. The crosses are the standard deviations of the average values.



Data: Intergovernmental Panel on Climate Change 2013
Analysis: Gonzalez et al. 2018 Environmental Research Letters

Figure 7. Projected change in annual average temperature, 2000-2100, at 800 m spatial resolution, for the highest emissions scenario (RCP8.5) for the average of 33 general circulation models (IPCC 2013, Gonzalez et al. 2018).

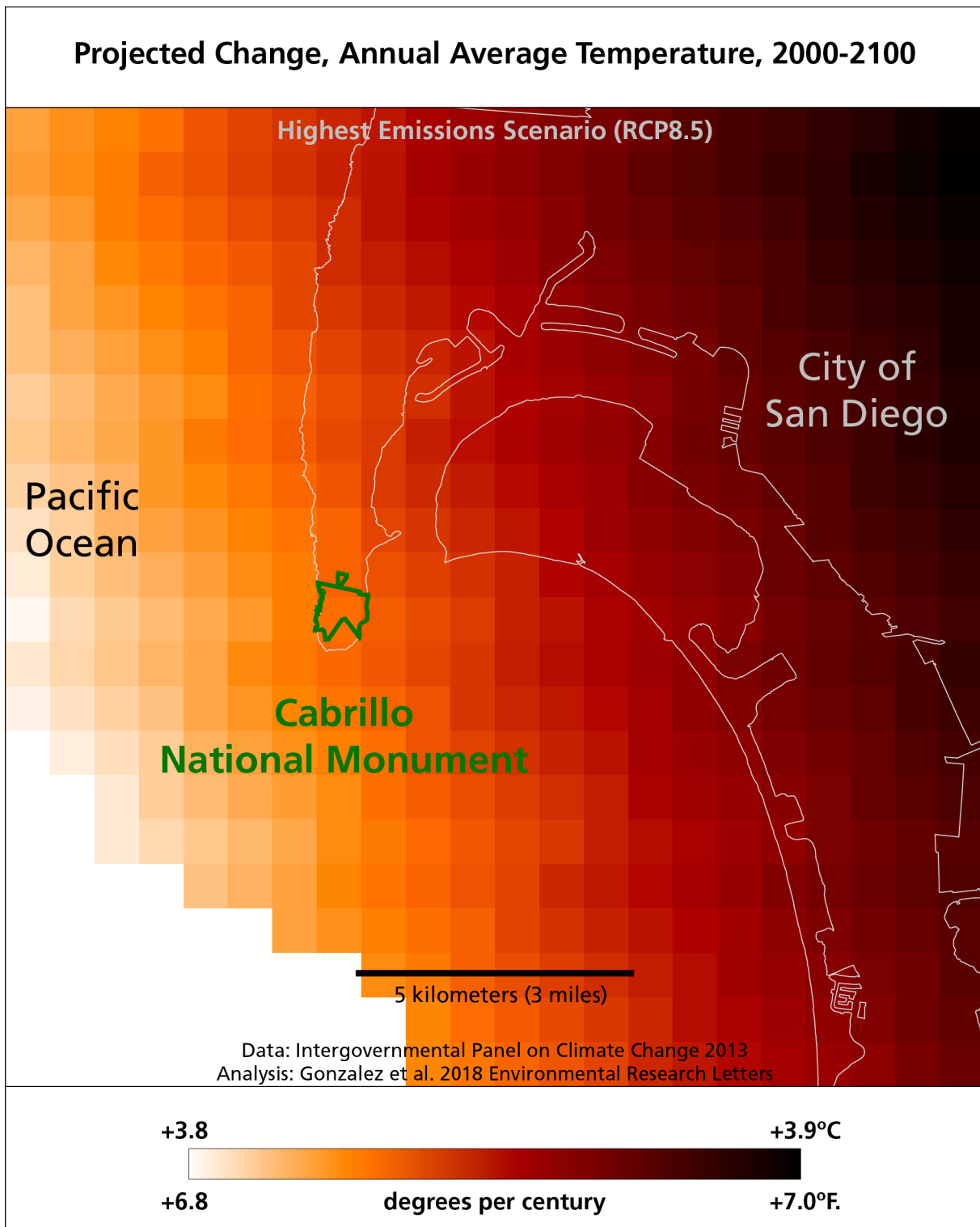


Figure 8. Projected change in total annual precipitation, 2000-2100, at 800 m spatial resolution, for the highest emissions scenario (RCP8.5) for the average of 33 general circulation models (IPCC 2013, Gonzalez et al. 2018).

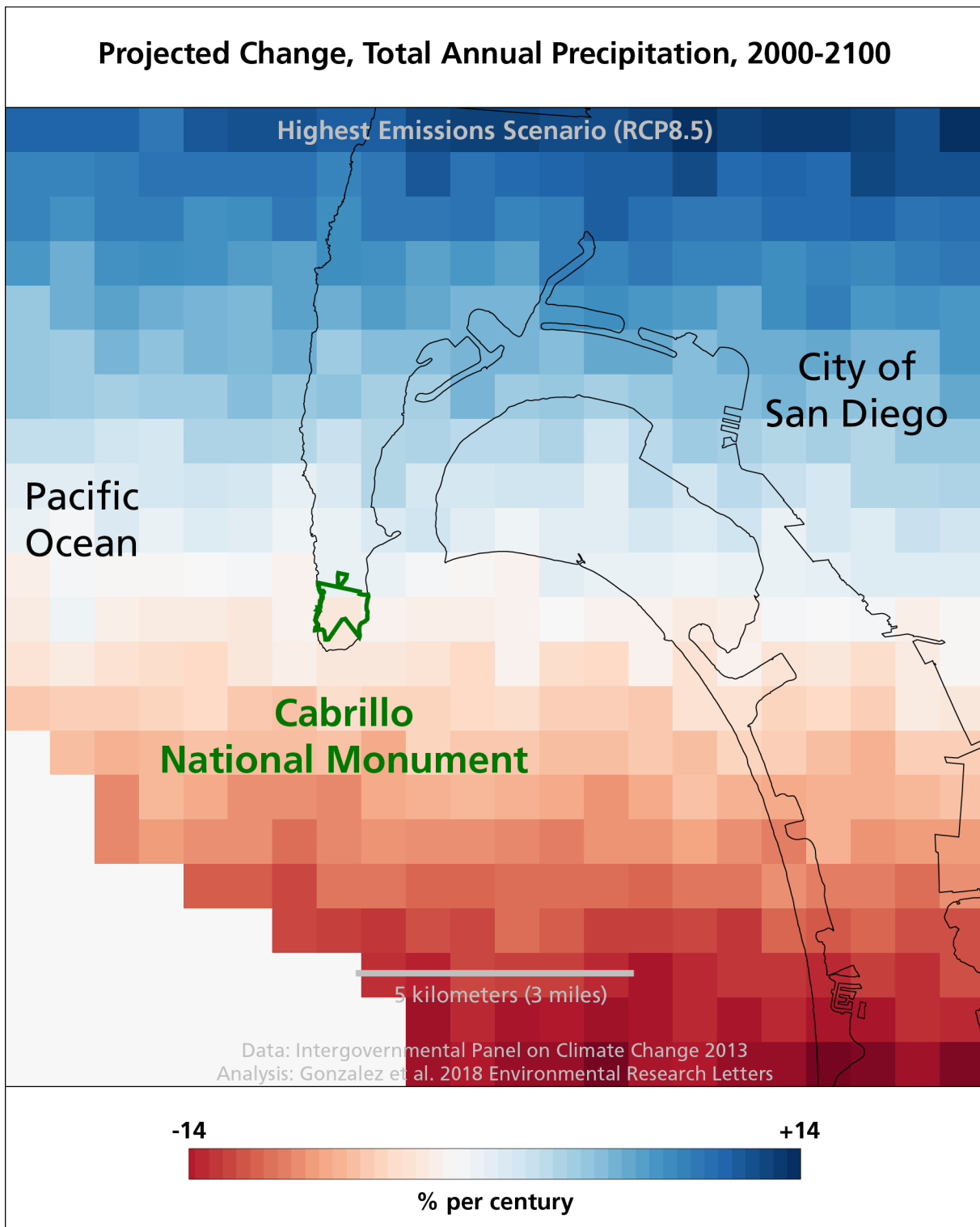


Figure 9. Historical sea level rise, tidal range, and storm surge and projected sea level rise under two emissions scenarios, at San Diego, California. The combination of past and projected sea level rise, daily tidal range, and storm surge could raise sea level up to 3.5 m above historical levels by 2100.

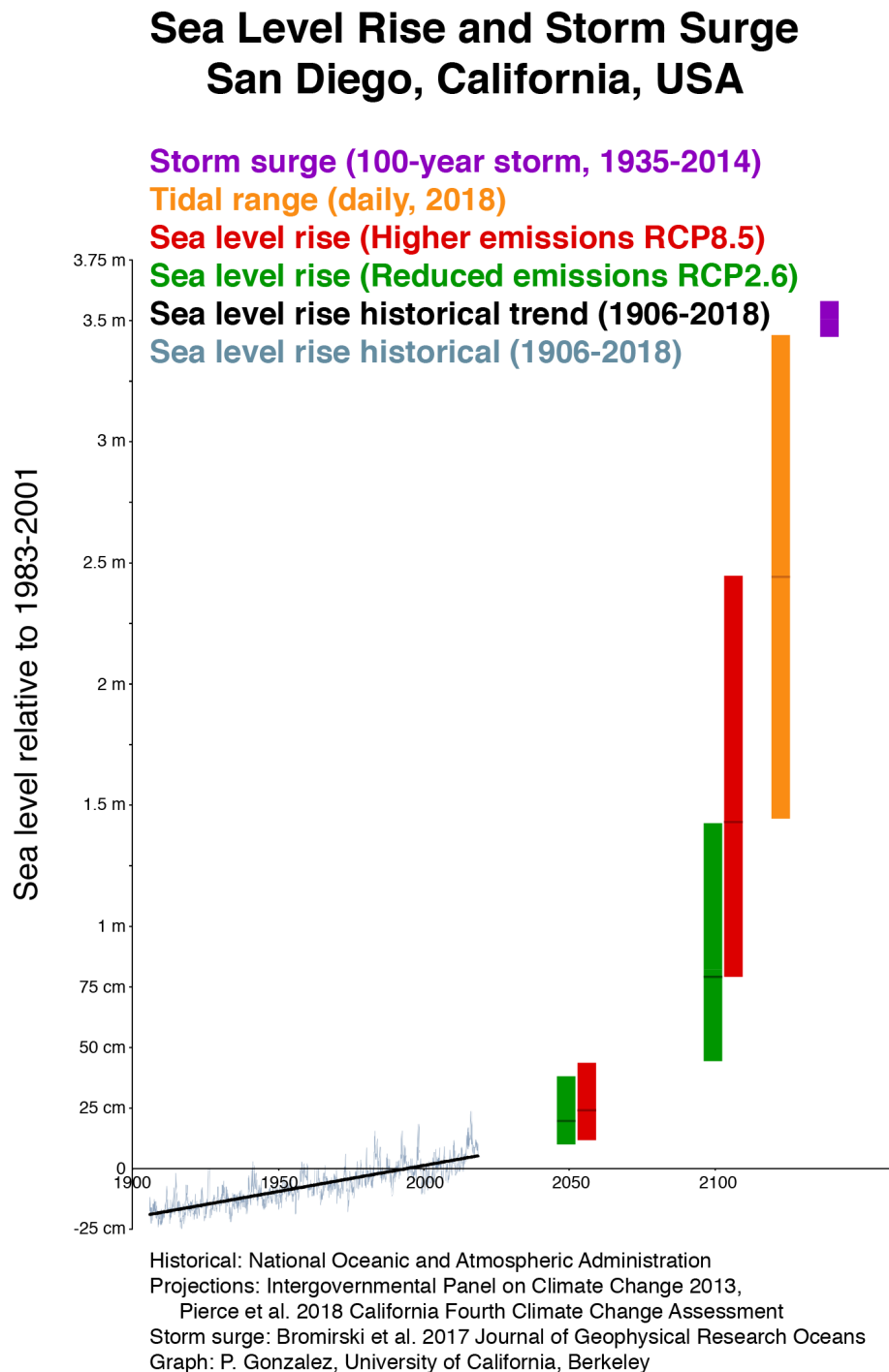


Figure 10. Aerial image of Cabrillo National Monument, from <<https://maps.nps.gov/slr>>, showing recent conditions.



Figure 11. Projected sea level under the highest emissions scenario (RCP8.5) (Caffrey et al. 2018). Sea level is shown at the highest tide, known as Mean Higher High Water, the 1983-2001 average of the higher high water height of each tidal day. Image from <<https://maps.nps.gov/slr>>



Table 1. Historical average temperatures and trends for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018). SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	17.5	0.7	1.8	0.4	***	1.8	1	
December-February	14.3	1	2.1	0.4	***	1.7	0.9	
March-May	16.3	1	1.8	0.4	***	2.5	1.1	*
June-August	20.3	0.9	1.1	0.4	**	1.8	1	
September-November	18.9	0.9	2.1	0.4	***	1.2	0.9	
January	14.2	1.1	2.7	0.5	***	3	1.1	**
February	14.6	1.2	2	0.4	***	2	1	*
March	15.1	1.1	1.7	0.4	***	3	1	**
April	16.2	1.2	1.9	0.5	***	2.2	1.4	
May	17.5	1.2	1.6	0.4	***	2.5	0.9	**
June	18.9	1.1	0.9	0.4	*	2.5	1	*
July	20.6	1.1	1	0.4	**	1.4	1.1	
August	21.6	1.1	1.4	0.4	**	1.5	1.1	
September	21.1	1.3	2.2	0.5	***	1.4	1.2	
October	19.2	1	2.4	0.5	***	1.1	1	
November	16.4	1.2	1.7	0.4	***	1.2	0.8	
December	14.2	1.1	1.7	0.5	**	0	0.9	

Table 2. Historical average precipitation totals and trends for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018). No trends were statistically significant. SD = standard deviation, SE = standard error.

	1971-2000		1895-2010		1950-2010	
	mean	SD	trend	SE	trend	SE
	mm y ⁻¹		% century ⁻¹		% century ⁻¹	
Annual	260	104	-11	12	31	31
December-February	136	81	-15	15	64	39
March-May	75	51	-14	20	-26	54
June-August	4	9	27	53	-87	149
September-November	46	33	-4	19	-9	60
January	54	56	-26	30	-4	69
February	50	46	4	25	170	59
March	53	46	-5	28	-15	86
April	17	18	-5	33	-24	62
May	6	9	-96	48	-115	107
June	2	4	24	51	28	125
July	1	1	85	83	351	214
August	2	8	13	126	-370	363
September	6	11	9	64	-62	152
October	15	16	-22	32	168	109
November	25	25	8	30	-100	86
December	30	25	-13	27	70	84

**

Table 3. Projected temperature increases (°C), 2000 to 2050, for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.3	0.5	1.6	0.5	1.5	0.4	2.1	0.5
December-February	1.3	0.5	1.7	0.5	1.5	0.4	2.1	0.6
March-May	1.3	0.4	1.5	0.6	1.4	0.4	1.8	0.6
June-August	1.3	0.6	1.5	0.7	1.4	0.5	1.9	0.7
September-November	1.5	0.5	1.9	0.8	1.7	0.5	2.6	0.9
January	1.3	0.5	1.7	0.5	1.5	0.5	2.1	0.6
February	1.3	0.4	1.5	0.5	1.3	0.5	1.9	0.5
March	1.2	0.4	1.4	0.5	1.3	0.5	1.8	0.6
April	1.2	0.5	1.4	0.7	1.4	0.4	1.8	0.7
May	1.4	0.5	1.6	0.8	1.4	0.5	1.9	0.7
June	1.2	0.6	1.4	0.8	1.4	0.5	1.8	0.8
July	1.1	0.7	1.3	0.7	1.2	0.6	1.8	0.8
August	1.5	0.7	1.7	0.7	1.6	0.5	2.1	0.7
September	1.5	0.6	1.9	0.6	1.7	0.6	2.5	0.8
October	1.5	0.5	1.9	1	1.6	0.5	2.6	1
November	1.5	0.6	2	1.1	1.7	0.5	2.6	1.3
December	1.3	0.5	1.8	1	1.6	0.5	2.4	1.1

Table 4. Projected temperature increases (°C), 2000 to 2100, for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.4	0.6	2.2	0.6	2.5	0.7	3.8	0.9
December-February	1.4	0.5	2.2	0.7	2.5	0.8	3.8	1
March-May	1.3	0.5	1.9	0.6	2.3	0.7	3.4	0.8
June-August	1.2	0.8	1.9	0.8	2.3	0.8	3.5	1
September-November	1.5	0.7	2.6	1	2.8	0.8	4.5	1.3
January	1.4	0.6	2.2	0.7	2.5	0.8	3.8	1
February	1.3	0.6	2	0.7	2.4	0.7	3.5	0.8
March	1.4	0.6	1.9	0.6	2.3	0.7	3.4	0.9
April	1.2	0.6	1.8	0.6	2.3	0.7	3.4	0.8
May	1.3	0.6	2	0.7	2.4	0.8	3.5	0.9
June	1.2	0.7	1.8	0.9	2.2	0.8	3.3	1
July	1.1	0.8	1.8	0.8	2.1	0.9	3.4	1
August	1.3	0.8	2.1	0.8	2.6	0.9	3.8	1.1
September	1.5	0.8	2.5	0.9	2.8	0.9	4.3	1.1
October	1.6	0.8	2.7	1.2	2.8	0.9	4.6	1.4
November	1.5	0.7	2.6	1.4	2.8	0.8	4.5	1.6
December	1.5	0.6	2.3	1.2	2.6	0.9	4.1	1.5

Table 5. Projected precipitation changes (%), 2000 to 2050, for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	4	13	2	12	2	16	1	16
December-February	5	20	4	21	7	28	7	25
March-May	-3	16	-4	21	-7	18	-10	28
June-August	17	40	27	35	13	40	28	54
September-November	7	25	2	29	5	23	-4	29
January	13	28	9	33	13	41	19	40
February	0	29	4	25	6	30	6	31
March	-1	21	-4	24	-2	26	-7	28
April	-2	27	-3	32	-14	22	-17	45
May	-11	48	2	61	-6	46	-2	66
June	13	57	14	84	0	81	5	88
July	46	80	41	93	40	72	50	94
August	14	65	39	68	23	96	43	98
September	22	55	42	81	21	59	35	67
October	27	45	15	49	28	48	11	62
November	-2	24	-11	41	-4	25	-18	31
December	5	24	-2	23	-1	25	-8	28

Table 6. Projected precipitation changes (%), 2000 to 2100, for the area within the boundaries of Cabrillo National Monument (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	4	12	2	12	-3	16	0	19
December-February	3	18	7	19	3	29	9	32
March-May	3	19	-9	19	-14	17	-19	27
June-August	22	39	25	43	11	55	32	68
September-November	11	22	4	32	-6	23	-1	29
January	11	29	16	29	14	45	21	45
February	-3	23	7	27	-3	30	9	37
March	2	26	-8	19	-7	22	-13	27
April	8	35	-9	33	-21	24	-27	36
May	9	54	-5	54	-24	49	-33	54
June	19	61	16	71	17	91	5	66
July	47	107	55	109	40	112	71	133
August	22	74	30	75	15	79	45	117
September	38	58	26	63	23	68	26	66
October	26	50	15	53	25	56	22	70
November	0	26	-3	38	-22	23	-14	34
December	-2	18	-7	24	-3	23	-6	29

References

- Abatzoglou, J.T. and A.P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences of the USA* 113: 11 770-11 775.
- Abraham, J.P., M. Baringer, N.L. Bindoff, T. Boyer, L.J. Cheng, J.A. Church, J.L. Conroy, C.M. Domingues, J.T. Fasullo, J. Gilson, G. Goni, S.A. Good, J.M. Gorman, V. Gouretski, M. Ishii, G.C. Johnson, S. Kizu, J.M. Lyman, A.M. Macdonald, W.J. Minkowycz, S.E. Moffitt, M.D. Palmer, A.R. Piola, F. Reseghetti, K. Schuckmann, K.E. Trenberth, I. Velicogna, and J.K. Willis. 2013. A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change. *Reviews of Geophysics* 51: 450-483.
- Alexander, M.A., J.D. Scott, K.D. Friedland, K.E. Mills, J.A. Nye, A.J. Pershing, and A.C. Thomas. 2018. Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. *Elementa: Science of the Anthropocene* 6: 9. doi:10.1525/elementa.191.
- Anacker, B.L., M. Gogol-Prokurat, K. Leidholm, and S. Schoenig. 2013. Climate change vulnerability assessment of rare plants in California. *Madroño* 60: 193-210.
- Ault, T.R., J.S. Mankin, B.I. Cook, and J.E. Smerdon. 2016. Relative impacts of mitigation, temperature, and precipitation on 21st-century megadrought risk in the American Southwest. *Science Advances* 2: e1600873. doi:10.1126/sciadv.1600873.
- Bauder, E.T. 2000. Recovery and management of Orcutt's spineflower (*Chorizanthe orcuttiana*). Report to the California Department of Fish and Game. San Diego State University, San Diego, CA.
- Barrows, C.W. and M. Fisher. 2014. Past, present and future distributions of a local assemblage of congeneric lizards in southern California. *Biological Conservation* 180: 97-107.
- Barry, J.P., C.H. Baxter, R.D. Sagarin, and S.E. Gilman. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* 267: 672-675.
- Bednaršek, N., R.A. Feely, J.C.P. Reum, B. Peterson, J. Menkel, S.R. Alin, and B. Hales. 2014. *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. *Proceedings of the Royal Society B* 281: 20140123. doi:10.1098/rspb.2014.0123.
- Bednaršek, N., R.A. Feely, N. Tolimieri, A.J. Hermann, S.A. Siedlecki, G.G. Waldbusser, P. McElhany, S.R. Alin, T. Klinger, B. Moore-Maley, and H.O. Pörtner. 2017. Exposure history determines pteropod vulnerability to ocean acidification along the US West Coast. *Scientific Reports* 7: 4526. doi: 10.1038/s41598-017-03934-z.
- Ben-Horin, T., H.S. Lenihan, and K.D. Lafferty. 2013. Variable intertidal temperature explains why disease endangers black abalone. *Ecology* 94: 161-168.
- Boch, C.A., S.Y. Litvin, F. Micheli, G. De Leo, E.A. Aalto, C. Lovera, C.B. Woodson, S. Monismith, and J.P. Barry. 2017. Effects of current and future coastal upwelling conditions on the fertilization success of the red abalone (*Haliotis rufescens*). *International Council for the Exploration of the Sea Journal of Marine Science* 74: 1125-1134.
- Bograd, S.J., M. Pozo Buil, E. Di Lorenzo, C.G. Castro, I.D. Schroeder, R. Goericke, C.R. Anderson, C. Benitez-Nelson, and F.A. Whitney. 2015. Changes in source waters to the Southern California Bight. *Deep Sea Research Part II: Topical Studies in Oceanography* 112: 42-52.
- Bolger, D.T., M.A. Patten, and D.C. Bostock. 2005. Avian reproductive failure in response to an extreme climatic

- p>event.
- Oecologia*
- 142: 398-406.
- Bradley, B.A., M. Oppenheimer, and D.S. Wilcove. 2009. Climate change and plant invasions: Restoration opportunities ahead? *Global Change Biology* 15: 1511-1521.
- Bromirski, P.D., R.E. Flick, and A.J. Miller. 2017. Storm surge along the Pacific coast of North America. *Journal of Geophysical Research Oceans* 122: 441-457.
- Busch, D.S., M. Maher, P. Thibodeau, and P. McElhany. 2014. Shell condition and survival of puget sound pteropods are impaired by ocean acidification conditions. *PLoS One* 9: e105884. doi:10.1371/journal.pone.0105884.
- Busse, L.B., E.L. Venrick, R. Antrobus, P.E. Miller, V. Vigilant, M.W. Silver, C. Mengelt, L. Mydlarz, and B.B. Prezelin. 2006. Domoic acid in phytoplankton and fish in San Diego, CA, USA. *Harmful Algae* 5: 91-101.
- Caffrey, M.A., R.L. Beavers, and C.H. Hoffman. 2018. Sea level rise and storm surge projections for the National Park Service. Report NPS/NRSS/NRR—2018/1648. National Park Service, Fort Collins, CO.
- California Department of Fish and Wildlife. 2016. A Rapid Assessment of the Vulnerability of Sensitive Wildlife to Extreme Drought. California Department of Fish and Wildlife, Sacramento, CA.
- Carter, B.R., R.A. Feely, S. Mecking, J.N. Cross, A.M. Macdonald, S.A. Siedlecki, L.D. Talley, C.L. Sabine, F.J. Millero, J.H. Swift, A.G. Dickson, and K.B. Rodgers. 2017. Two decades of Pacific anthropogenic carbon storage and ocean acidification along Global Ocean Ship-based Hydrographic Investigations Program sections P16 and P02. *Global Biogeochemical Cycles* 31: 306-327.
- Cavole, L.M., A.M. Demko, R.E. Diner, A. Giddings, I. Koester, C.M.L.S. Pagniello, M.L. Paulsen, A. Ramirez-Valdez, S.M. Schwenck, N.K. Yen, M.E. Zill, and P.J.S. Franks. 2016. Biological impacts of the 2013–2015 warm-water anomaly in the Northeast Pacific: Winners, losers, and the future. *Oceanography* 29: 273-285.
- Chan, F., J.A. Barth, C.A. Blanchette, R.H. Byrne, F. Chavez, O. Cheriton, R.A. Feely, G. Friederich, B. Gaylord, T. Gouhier, S. Hacker, T. Hill, G. Hofmann, M.A. McManus, B.A. Menge, K.J. Nielsen, A. Russell, E. Sanford, J. Sevadjan, L. Washburn. 2017. Persistent spatial structuring of coastal ocean acidification in the California Current System. *Scientific Reports* 7: 2526. doi:10.1038/s41598-017-02777-y.
- Cheng, L., J. Abraham, Z. Hausfather, and K.E. Trenberth. 2019. How fast are the oceans warming? *Science* 363: 128-129.
- Cheng, L., K.E. Trenberth, J. Fasullo, T. Boyer, J. Abraham, and J. Zhu. 2017. Improved estimates of ocean heat content from 1960 to 2015. *Science Advances* 3: e1601545. doi:10.1126/sciadv.1601545.
- Cheung, W.W.L., R.D. Brodeur, T.A. Okey, and D. Pauly. 2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. *Progress in Oceanography* 130: 19-31.
- Church, J.A. and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st Century. *Surveys in Geophysics* 32: 585-602.
- Clemesha, R.E.S., A. Gershunov, S.F. Iacobellis, A.P. Williams, and D.R. Cayan. 2016. The northward march of summer low cloudiness along the California coast. *Geophysical Research Letters* 43: 1287-1295.
- Cook, B.I., T.R. Ault, J.E. Smerdon. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Science Advances* 1: e1400082. doi:10.1126/sciadv.1400082.
- Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28: 2031-2064.
- Dangendorf, S., M. Marcos, G. Wöppelmann, C.P. Conrad, T. Frederikse, and R. Riva. 2017. Reassessment of 20th

- century global mean sea level rise. *Proceedings of the National Academy of Sciences of the USA* 114: 5946-5951.
- Davidson, A.M., M. Jennions, and A.B. Nicotra. 2011. Do invasive species show higher phenotypic plasticity than native species and, if so, is it adaptive? A meta-analysis. *Ecology Letters* 14: 419-431.
- Diffenbaugh, N.S., D.L. Swain, and D. Touma. 2015. Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences of the USA* 112: 3931-3936.
- Early, R., B.A. Bradley, J.S. Dukes, J.J. Lawler, J.D. Olden, D.M. Blumenthal, P. Gonzalez, E.D. Grosholz, I. Ibañez, L.P. Miller, C.J.B. Sorte, and A.J. Tatem. 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Communications* 7: 12485. doi:10.1038/ncomms12485.
- Easterling, D.R., J.R. Arnold, T. Knutson, K.E. Kunkel, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner. 2017. Precipitation change in the United States. In U.S. Global Change Research Program (USGCRP). *Climate Science Special Report: Report: Fourth National Climate Assessment, Volume I*. [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)] USGCRP, Washington, DC.
- Emery, N.C., C.M. D'Antonio, and C.J. Still. 2018. Fog and live fuel moisture in coastal California shrublands. *Ecosphere* 9: e02167. doi:10.1002/ecs2.2167.
- Espeset, A.E., J.G. Harrison, A.M. Shapiro, C.C. Nice, J.H. Thorne, D.P. Waetjen, J.A. Fordyce, and M.L. Forister. 2016. Understanding a migratory species in a changing world: climatic effects and demographic declines in the western monarch revealed by four decades of intensive monitoring. *Oecologia* 181: 819-830.
- Feely, R.A., S. Alin, B. Carter, N. Bednaršek, B. Hales, F. Chan, T.M. Hill, B. Gaylord, E. Sanford, R.H. Byrne, C.L. Sabine, D. Greeley, and L. Juranek. 2016. Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal, and Shelf Science* 183: 260-270.
- Flesch, A.D., P.C. Rosen, and P. Holm. 2017. Long-term changes in abundances of Sonoran Desert lizards reveal complex responses to climatic variation. *Global Change Biology* 23: 5492–5508.
- Frölicher, T.L., E.M. Fischer, and N. Gruber. 2018. Marine heatwaves under global warming. *Nature* 560: 360-364.
- Gobler, C.J., O.M. Doherty, T.K. Hattenrath-Lehmann, A.W. Griffith, Y. Kang, and R.W. Litaker. 2017. Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. *Proceedings of the National Academy of Sciences of the USA* 114: 4975-4980.
- Goldstein, L.J. and K.N. Suding. 2014. Intra-annual rainfall regime shifts competitive interactions between coastal sage scrub and invasive grasses. *Ecology* 95: 425-435.
- Gonzalez, P. 2017. Climate change trends, impacts, and vulnerabilities in US national parks. In Beissinger, S.R., D.D. Ackerly, H. Doremus, and G.E. Machlis (eds.) *Science, Conservation, and National Parks*. University of Chicago Press, Chicago, IL.
- Gonzalez, P., J.J. Battles, B.M. Collins, T. Robards, and D.S. Saah. 2015. Aboveground live carbon stock changes of California wildland ecosystems, 2001-2010. *Forest Ecology and Management* 348: 68-77.
- Gonzalez, P., F. Wang, M. Notaro, D.J. Vimont, and J.W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. *Environmental Research Letters* 13: 104001. doi:10.1088/1748-9326/aade09.
- Gruber, N., C. Hauri, Z. Lachkar, D. Loher, T.L. Frolicher, and G.K. Plattner. 2012. Rapid progression of ocean acidification in the California Current System. *Science* 337: 220-223.

- Hagos, S.M., L.R. Leung, J.H. Yoon, J. Lu, and Y. Gao. 2016. A projection of changes in landfalling atmospheric river frequency and extreme precipitation over western North America from the Large Ensemble CESM simulations. *Geophysical Research Letters* 43: 1357-1363.
- Harada, A.E., T.M. Healy, and R.S. Burton. 2019. Variation in thermal tolerance and its relationship to mitochondrial function across populations of *Tigriopus californicus*. *Frontiers in Physiology* 10: 213. doi:10.3389/fphys.2019.00213
- Harley, C.D.G. 2011. Climate change, keystone predation, and biodiversity loss. *Science* 334: 1124-1127.
- Harvell, C.D., D. Montecino-Latorre, J.M. Caldwell, J.M. Burt, K. Bosley, A. Keller, S.F. Heron, A.K. Salomon, L. Lee, O. Pontier, C. Pattengill-Semmens, and J.K. Gaydos. 2019. Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*). *Science Advances* 5: eaau7042. doi:10.1126/sciadv.aau7042.
- Hellmann, J.J., J.E. Byers, B.G. Bierwagen, and J.S. Dukes. 2008. Five potential consequences of climate change for invasive species. *Conservation Biology* 22: 534-543.
- Helmuth, B., N. Mieszkowska, P. Moore, and S.J. Hawkins. 2006. Living on the edge of two changing worlds: Forecasting the responses of rocky intertidal ecosystems to climate change. *Annual Review of Ecology, Evolution, and Systematics* 37: 373-404.
- Henson, S.A., C. Beaulieu, T. Ilyina, J.G. John, M. Long, R. Séférian, J. Tjiputra, and J.L. Sarmiento. 2017. Rapid emergence of climate change in environmental drivers of marine ecosystems. *Nature Communications* 8: 14682. doi:10.1038/ncomms14682.
- Hessburg, P.F., T.A. Spies, D.A. Perry, C.N. Skinner, A.H. Taylor, P.M. Brown, S.L. Stephens, A.J. Larson, D.J. Churchill, N.A. Povak, P.H. Singleton, B. McComb, W.J. Zielinski, B.M. Collins, R.B. Salter, J.J. Keane, J.F. Franklin, G. Riegel. 2016. Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. *Forest Ecology and Management* 366: 221-250.
- Holden, Z.A., A. Swanson, C.H. Luce, W.M. Jolly, M. Maneta, J.W. Oyster, D.A. Warren, R. Parsons, and D. Affleck. 2018. Decreasing fire season precipitation increased recent western US forest wildfire activity. *Proceedings of the National Academy of Sciences of the USA* 115: E8349-E8357.
- Hughes, M., A. Hall, and J. Kim. 2011. Human-induced changes in wind, temperature and relative humidity during Santa Ana events. *Climatic Change* 109:S119–S132.
- Hulton VanTassel, H.L., M.D. Bell, J. Rotenberry, R. Johnson, and M.F. Allen. 2017. Environmental change, shifting distributions, and habitat conservation plans: A case study of the California gnatcatcher. *Ecology and Evolution* 7: 10 326–10 338.
- Huxman, T.E., E.P. Hamerlynck, and S.D. Smith. 1999. Reproductive allocation and seed production in *Bromus madritensis* ssp. *rubens* at elevated atmospheric CO₂. *Functional Ecology* 13: 769-777.
- Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2018. *Global Warming of 1.5°C*. [Masson-Delmotte, V., P. Zhai,

- H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) IPCC, Geneva, Switzerland.
- Ishii, M. Y. Fukuda, S. Hirahara, S. Yasui, T. Suzuki, and K. Sato. 2017. Accuracy of global upper ocean heat content estimation expected from present observational data sets. *Science Online Letters on the Atmosphere* 13: 163–167.
- Ito, T., S. Minobe, M.C. Long, and C. Deutsch. 2017. Upper ocean O₂ trends: 1958–2015. *Geophysical Research Letters* 44: 4214–4223.
- Jacox, M.G., M.A. Alexander, N.J. Mantua, J.D. Scott, G. Hervieux, R.S. Webb, and F.E. Werner. 2018. Forcing of multiyear extreme ocean temperatures that impacted California current living marine resources in 2016. *Bulletin of the American Meteorological Society* 99: S27–S33.
- Jennings, M.K., D. Cayan, J. Kalansky, A.D. Pairis, D.M. Lawson, A.D. Syphard, U. Abeysekera, R.E.S. Clemesha, A. Gershunov, K. Guirguis, J.M. Randall, E.D. Stein, and S. Vanderplank. 2018. San Diego County Ecosystems: Ecological Impacts of Climate Change on a Biodiversity Hotspot. California Fourth Climate Change Assessment, Report CCCA4-EXT-2018-010. San Diego State University, San Diego, CA.
- Jeon, S., Prabhat, S. Byna, J. Gu, W.D. Collins, and M.F. Wehner. 2015. Characterization of extreme precipitation within atmospheric river events over California. *Advances in Statistical Climatology, Meteorology, and Oceanography* 1: 45–57.
- Jin, Y., J.T. Randerson, N. Faivre, S. Capps, A. Hall, and M.L. Goulden. 2014. Contrasting controls on wildland fires in Southern California during periods with and without Santa Ana winds. *Journal of Geophysical Research Biogeosciences* 119: 432–450.
- Kalansky, J., D. Cayan, K. Barba, L. Walsh, K. Brouwer, and D. Boudreau. 2018. San Diego Summary Report. California Fourth Climate Change Assessment, Report SUM-CCCA4-2018-009, Sacramento, CA.
- Keeley, J.E., M. Baer-Keeley, and C.J. Fotheringham. 2005. Alien plant dynamics following fire in Mediterranean-climate California shrublands. *Ecological Applications* 15: 2109–2125.
- Keeley, J.E. and T.J. Brennan. 2012. Fire-driven alien invasion in a fire-adapted ecosystem. *Oecologia* 169: 1043–1052.
- Keeley, J.E., and A.D. Syphard. 2017. Different historical fire–climate patterns in California. *International Journal of Wildland Fire* 26: 253–268.
- Keeley, J.E. and P.H. Zedler. 2009. Large, high-intensity fire events in southern California shrublands: debunking the fine-grain age patch model. *Ecological Applications* 19: 69–94.
- Kelly, M.W., E. Sanford, and R.K. Grosberg. 2012. Limited potential for adaptation to climate change in a broadly distributed marine crustacean. *Proceedings of the Royal Society of London B* 279: 349–356.
- Koslow, J.A., H. McMonagle, and W. Watson. 2017. Influence of climate on the biodiversity and community structure of fishes in the southern California Current. *Marine Ecology Progress Series* 571:193–206.
- Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner. 2017. Extreme storms. In U.S. Global Change Research Program (USGRP). Climate Science Special Report. Fourth National Climate Assessment, Volume I. [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)] USGCRP, Washington, DC.
- Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J. Gattuso. 2013. Impacts

- of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology* 19: 1884-1896.
- Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 5. Climate of the Southwest. U.S. National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-5, Washington, DC.
- La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. *Ecology* 88: 1803-1812.
- Langham, G.M., J.G. Schuetz, T. Distler, C.U. Soykan, and C. Wilsey. 2015. Conservation status of North American birds in the face of future climate change. *PLoS One* 10: e0135350. doi:10.1371/journal.pone.0135350.
- Lavers, D.A., M.F. Ralph, D.E. Waliser, A. Gershunov, and M.D. Dettinger. 2015. Climate change intensification of horizontal water vapor transport in CMIP5. *Geophysical Research Letters* 42: 5617-5625.
- Lawson, D.M., H.M. Regan, P.H. Zedler, and J. Franklin. 2010. Cumulative effects of land use, altered fire regime and climate change on persistence of *Ceanothus verrucosus*, a rare, fire-dependent plant species. *Global Change Biology* 16: 2518-2529.
- Levitus, S., J.I. Antonov, T.P. Boyer, O.K. Baranova, H.E. Garcia, R.A. Locarnini, A.V. Mishonov, J.R. Reagan, D. Seidov, E.S. Yarosh, and M.M. Zweng. 2012. World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010. *Geophysical Research Letters* 39: L10603. doi:10.1029/2012GL051106.
- Lewitus, A.J., R.A. Horner, D.A. Caron, E. Garcia-Mendoza, B.M. Hickey, M. Hunter, D.D. Huppert, R.M. Kudela, G.W. Langlois, J.L. Largier, E.J. Lessard, R. RaLonde, J.E.J. Rensel, P.G. Strutton, V.L. Trainer, J.F. Tweddle. 2012. Harmful algal blooms along the North American west coast region: History, trends, causes, and impacts. *Harmful Algae* 19: 133-159.
- Lippitt, C.L., D.A. Stow, J.F. O'Leary, and J. Franklin. 2012. Influence of short-interval fire occurrence on post-fire recovery of fire-prone shrublands in California, USA. *International Journal of Wildland Fire* 22: 184-193.
- Liu, Y., A.M.O. Oduor, Z. Zhang, A. Manea, I.M. Tooth, M.R. Leishman, X. Xu, and M. van Kleunen. 2017. Do invasive alien plants benefit more from global environmental change than native plants? *Global Change Biology* 23: 3363-3370.
- Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. *Ecological Applications* 19: 1003-1021.
- Long, M.C., C. Deutsch, and T. Ito. 2016. Finding forced trends in oceanic oxygen. *Global Biogeochemical Cycles* 30: 381-397.
- Mann, M.L., E. Batllori, M.A. Moritz, E.K. Waller, P. Berck, A.L. Flint, L.E. Flint, and E. Dolfi. 2016. Incorporating anthropogenic influences into fire probability models: Effects of human activity and climate change on fire activity in California. *PLoS ONE* 11: e0153589. doi:10.1371/journal.pone.0153589.
- Marshall, K.N., I.C. Kaplan, E.E. Hodgson, A. Hermann, D.S. Busch, P. McElhany, T.E. Essington, C.J. Harvey, and E.A. Fulton. 2017. Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections. *Global Change Biology* 23: 1525-1539.
- McCabe, R.M., B.M. Hickey, R.M. Kudela, K.A. Lefebvre, N.G. Adams, B.D. Bill, F.M.D. Gulland, R.E. Thomson, W.P. Cochlan, and V.L. Trainer. 2016. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters* 43: 10 366-10 376.

- McClatchie, S., R. Goericke, R. Cosgrove, G. Auad, and R. Vetter. 2010. Oxygen in the Southern California Bight: Multidecadal trends and implications for demersal fisheries. *Geophysical Research Letters* 37: L19602. doi:10.1029/2010GL044497.
- McKibben, S.M., W. Peterson, A.M. Wood, V.L. Trainer, M. Hunter, and A.E. White. 2017. Climatic regulation of the neurotoxin domoic acid. *Proceedings of the National Academy of Sciences* 114: 239-244.
- Miner, C.M. J.L. Burnaford, R.F. Ambrose, L. Antrim, H. Bohlmann, C.A. Blanchette, J.M. Engle, S.C. Fradkin, R. Gaddam, C.D.G. Harley, B.G. Miner, S.N. Murray, J.R. Smith, S.G. Whitaker, and P.T. Raimondi. 2018. Large-scale impacts of sea star wasting disease (SSWD) on intertidal sea stars and implications for recovery. *PLoS One* 13: e0192870. doi:10.1371/journal.pone.0192870.
- Moore, S.E. and H.P. Huntington. 2008. Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications* 18: S157-S165.
- Moore, S.E., K.M. Wynne, J.C. Kinney, and J.M. Grebmeier. 2007. Gray whale occurrence and forage southeast of Kodiak Island, Alaska. *Marine Mammal Science* 23: 419-428.
- Moore, S.K., V.L. Trainer, N.J. Mantua, M.S. Parker, E.A. Laws, L.C. Backer, and L.E. Fleming. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. *Environmental Health* 7: S4. doi:10.1186/1476-069X-7-S2-S4.
- Moritz, M.A., M.A. Parisien, E. Batllori, M.A. Krawchuk, J. Van Dorn, D.J. Ganz, and K. Hayhoe. 2012. Climate change and disruptions to global fire activity. *Ecosphere* 3: art49. doi:10.1890/ES11-00345.1.
- Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, and T.J. Wilbanks. 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463: 747-756.
- National Park Service (NPS). 2010. Climate Friendly Parks. Cabrillo National Monument Action Plan. National Park Service, Washington, DC.
- National Park Service (NPS). 2018. NPSpecies, Park Species List, Cabrillo National Monument. <https://irma.nps.gov/NPSpecies/Search/SpeciesList/CABR>.
- Neuman, M., B. Tissot, and G. Vanblaricom. 2010. Overall status and threats assessment of black abalone (*Haliotis cracherodii* Leach, 1814) populations in California. *Journal of Shellfish Research* 29: 577-586.
- O'Neil, J.M., T.W. Davis, M.A. Burford, and C.J. Gobler. 2012. The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. *Harmful Algae* 14: 313-334.
- Paprocki, N., J.A. Heath, and S.J. Novak. 2014. Regional distribution shifts help explain local changes in wintering raptor abundance: Implications for interpreting population trends. *PLOS One* 9: e86814. doi:10.1371/journal.pone.0086814.
- Pierce, D.W., J.F. Kalansky, and D.R. Cayan. 2018. Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California Fourth Climate Change Assessment, Report CNRA-CEC-2018-006. Scripps Institution of Oceanography, San Diego, CA.
- Polade, S.D., A. Gershunov, D.R. Cayan, M.D. Dettinger, and D.W. Pierce. 2017. Precipitation in a warming world: assessing projected hydro-climate changes in California and other Mediterranean climate regions. *Scientific Reports* 7:10783. doi:10.1038/s41598-017-11285-y.
- Polade, S.D., D.W. Pierce, D.R. Cayan, A. Gershunov, and M.D. Dettinger. 2014. The key role of dry days in

- changing regional climate and precipitation regimes. *Scientific Reports* 4: 4364. doi:10.1038/srep04364.
- Preston, K.L. and J.T. Rotenberry. 2006. The role of food, nest predation, and climate in timing of wrenit reproductive activities. *Condor* 108: 832-841.
- Rachels, D.H., D.A. Stow, J.F. O'Leary, H.D. Johnson, and P.J. Riggan. 2016. Chaparral recovery following a major fire with variable burn conditions. *International Journal of Remote Sensing* 37: 3836-3857.
- Rapacciuolo, G., S.P. Maher, A.C. Schneider, T.T. Hammond, M.D. Jabis, R.E. Walsh, K.J. Iknayan, G.K. Walden, M.F. Oldfather, D.D. Ackerly, and S.R. Beissinger. 2014. Beyond a warming fingerprint: Individualistic biogeographic responses to heterogeneous climate change in California. *Global Change Biology* 20: 2841-2855.
- Resplandy, L., R.F. Keeling, Y. Eddebbar, M.K. Brooks, R. Wang, L. Bopp, M.C. Long, J.P. Dunne, W. Koeve, and A. Oschlies. 2018. Quantification of ocean heat uptake from changes in atmospheric O₂ and CO₂ composition. *Nature* 563: 105-108.
- Riordan, E.C. and P.W. Rundel. 2014. Land use compounds habitat losses under projected climate change in a threatened California ecosystem. *PLoS ONE* 9: e86487. doi:10.1371/journal.pone.0086487.
- Rogers-Bennett, L., R.F. Dondanville, J.D. Moore, and L.I. Vilchis. 2010. Response of red abalone reproduction to warm water, starvation, and disease stressors: Implications of ocean warming. *Journal of Shellfish Research* 29: 599-611.
- Sagarin, R.D., J.P. Barry, S.E. Gilman, and C.H. Baxter. 1999. Climate-related change in an intertidal community over short and long time scales. *Ecological Monographs* 69: 465-490.
- Salvadeo, C.J., U.A. Gómez-Gallardo, M. Nájera-Caballero, J. Urbán-Ramirez, and D. Lluch-Belda. 2015. The effect of climate variability on gray whales (*Eschrichtius robustus*) within their wintering areas. *PLoS One* 10: e0134655. doi:10.1371/journal.pone.0134655.
- Sandel, B. and E.M. Dangremond. 2012. Climate change and the invasion of California by grasses. *Global Change Biology* 18: 277-289.
- Schmidtko, S., L. Stramma, and M. Visbeck. 2017. Decline in global oceanic oxygen content during the past five decades. *Nature* 542: 335-339.
- Scholin, C.A., F. Gulland, G.J. Doucette, S. Benson, M. Busman, F.P. Chavez, J. Cordaro, R. DeLong, A. De Vogelaere, J. Harvey, M. Haulena, K. Lefebvre, T. Lipscomb, S. Loscutoff, L.J. Lowenstine, R. Marin, P.E. Miller, W.A. McLellan, P.D.R. Moeller, C.L. Powell, T. Rowles, P. Silvagni, M. Silver, T. Spraker, V. Trainer, and F.M. Van Dolah. 2000. Mortality of sea lions along the central California coast linked to a toxic diatom bloom. *Nature* 403: 80-84.
- Schwartz, R.E., A. Gershunov, S.F. Iacobellis, and D.R. Cayan. 2014. North American west coast summer low cloudiness: Broad-scale variability associated with sea surface temperature. *Geophysical Research Letters* 41: 3307-3314.
- Serafin, K.A., P. Ruggiero, and H.F. Stockdon. 2017. The relative contribution of waves, tides, and nontidal residuals to extreme total water levels on U.S. West Coast sandy beaches. *Geophysical Research Letters* 44: 1839-1847.
- Shen, L., L.J. Mickley, and E. Gilleland. 2016. Impact of increasing heat waves on U.S. ozone episodes in the 2050s: Results from a multimodel analysis using extreme value theory. *Geophysical Research Letters* 43: 4017-4025. doi:10.1002/2016GL068432.

- Slangen, A.B.A., J.A. Church, C. Agosta, X. Fettweis, B. Marzeion, and K. Richter. 2016. Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change* 6: 701-705.
- Smith, J.R., P. Fong, and R.F. Ambrose. 2006. Dramatic declines in mussel bed community diversity: response to climate change? *Ecology* 87: 1153-1161.
- Stephens, S.L., N. Burrows, A. Buyantuyev, R.W. Gray, R.W., R.E. Keane, R. Kubian, S. Liu, F. Seijo, L. Shu, K.G. Tolhurst, and J.W. van Wagtenonk. 2014. Temperate and boreal forest mega-fires: Characteristics and challenges. *Frontiers in Ecology and the Environment* 12: 115-122.
- Theoharides, K.A. and J.S. Dukes. 2007. Plant invasion across space and time: Factors affecting nonindigenous species success during four stages of invasion. *New Phytologist* 176: 256-273.
- Timmermann, A., S.I. An, J.S. Kug, F.F. Jin, W. Cai, A. Capotondi, K.M. Cobb, M. Lengaigne, M.J. McPhaden, M.F. Stuecker, K.Stein, A.T. Wittenberg, K.S. Yun, T. Bayr, H.C. Chen, Y. Chikamoto, B. Dewitte, D. Dommenget, P. Grothe, E. Guilyardi, Y.G. Ham, M. Hayashi, S. Ineson, D. Kang, S. Kim, W. Kim, J.Y. Lee, T. Li, J.J. Luo, S. McGregor, Y. Planton, S. Power, H. Rashid, H.L. Ren, A. Santoso, K. Takahashi, A. Todd, G. Wang, G. Wang, R. Xie, W.H. Yang, S.W. Yeh, J. Yoon, E. Zeller, and X. Zhang. 2018. El Niño–Southern Oscillation complexity. *Nature* 559: 535-545.
- United Nations Framework Convention on Climate Change (UNFCCC). 2015. Adoption of the Paris Agreement. Document FCCC/CP/2015/10/Add1, Decision 1/CP21. UNFCCC, Bonn, Germany.
- United States Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. USGCRP, Washington, DC.
- United States Global Change Research Program (USGCRP). 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)] USGCRP, Washington, DC.
- Uyeda, K.A., D.A. Stow, J.F. O’Leary, I.T. Schmidt, P.J. Riggan, and N. Hölzel. 2016. Spatial variation of fuel loading within varying aged stands of chaparral. *Applied Vegetation Science* 19: 267-279.
- Vahmani, P., F. Sun, A. Hall, and G. Ban-Weiss. 2016. Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. *Environmental Research Letters* 11: 124027. doi:10.1088/1748-9326/11/12/124027.
- Vasey, M.C., M.E. Loik, and V.T. Parker. 2012. Influence of summer marine fog and low cloud stratus on water relations of evergreen woody shrubs (*Arctostaphylos*: Ericaceae) in the chaparral of central California. *Oecologia* 170: 325-337.
- Vilchis, L.I., M.J. Tegner, J.D. Moore, C.S. Friedman, K.L. Riser, T.T. Robbins, and P.K. Dayton. 2005. Ocean warming effects on growth, reproduction, and survivorship of southern California abalone. *Ecological Applications* 15: 469-480.
- Vose, R.S., S. Applequist, M. Squires, I. Durre, M.J. Menne, C.N. Williams, C. Fenimore, K. Gleason, and D. Arndt. 2014. Improved historical temperature and precipitation time series for U.S. climate divisions. *Journal of Applied Meteorology and Climatology* 53: 1232-1251.
- Warner, M.D., C.F. Mass, and E.P. Salathé. 2015. Changes in winter atmospheric rivers along the North American West Coast in CMIP5 climate models. *Journal of Hydrometeorology* 16: 118–128.
- Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande. 2017. Droughts, floods, and hydrology. In

- U.S. Global Change Research Program (USGCRP). Climate Science Special Report: Report: Fourth National Climate Assessment, Volume I. [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)] USGCRP, Washington, DC.
- Westerling, A.L., B.P. Bryant, H.K. Preisler, T.P. Holmes, H.G. Hidalgo, T. Das, and S.R. Shrestha. 2011. Climate change and growth scenarios for California wildfire. *Climatic Change* 109: S445-463.
- Williams, A.P., C.J. Still, D.T. Fischer, and S.W. Leavitt. 2008. The influence of summertime fog and overcast clouds on the growth of a coastal Californian pine: a tree-ring study. *Oecologia* 156: 601-611.
- Williams, A.P., R. Seager, J.T. Abatzoglou, B.I. Cook, J.E. Smerdon, and E.R. Cook. 2015. Contribution of anthropogenic warming to California drought during 2012–2014. *Geophysical Research Letters* 42: 6819-6828.
- Williams, A.P., P. Gentine, M.A. Moritz, D.A. Roberts, and J.T. Abatzoglou. 2018. Effect of reduced summer cloud shading on evaporative demand and wildfire in coastal Southern California. *Geophysical Research Letters* 45: 5653-5662.
- Wishner, K.F., B.A. Seibel, C. Roman, C. Deutsch, D. Outram, C.T. Shaw, M.A. Birk, K.A.S. Mislan, T.J. Adams, D. Moore, and S. Riley. 2018. Ocean deoxygenation and zooplankton: Very small oxygen differences matter. *Science Advances* 4: eaau5180. doi: 10.1126/sciadv.aau5180.
- Wood, A.W., L.R. Leung, V. Sridhar and D.P. Lettenmaier. 2004. Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change* 62: 189-216.
- Wu, J.X., C.B. Wilsey, L. Taylor, and G.W. Schuurman. 2018. Projected avifaunal responses to climate change across the U.S. National Park System. *PLoS ONE* 13 e0190557 doi:10.1371/journal.pone.0190557.
- Yeh, S.W., W. Cai, S.K. Min, M.J. McPhaden, D. Dommenget, B. Dewitte, M. Collins, K. Ashok, S.I. An, B.Y. Yim, and J.S. Kug. 2018. ENSO atmospheric teleconnections and their response to greenhouse gas forcing. *Reviews of Geophysics* 56: 185-206.
- Young, A.P. 2018. Decadal-scale coastal cliff retreat in southern and central California. *Geomorphology* 300: 164-175.
- Young, A.P., R.E. Flick, W.C. O'Reilly, D.B. Chadwick, W.C. Crampton, and J.J. Helly. 2014. Estimating cliff retreat in southern California considering sea level rise using a sand balance approach. *Marine Geology* 348: 15-26.